TECHNICAL ATTACHMENTS

TECHNICAL ATTACHMENT A
DETAILED TRANSPORT MECHANISMS

1.0 Introduction

Definition: **Air Pollution Transport can be defined as the advection of pollutants in air over long distances, typically beyond the immediate source area of about 10 to 20 miles.**

The term "Transport" is most commonly applied to ozone, small particles ($PM_{2.5}$), mercury, and airborne acids and is used when these air pollutants cross jurisdictional boundaries such as state or international borders. Here are two key questions which are central to the issue of air pollution transport:

- How do we know that air pollution transport is real?
- How much of a problem is it?

Scientists have been studying air pollution transport for decades - initially in an attempt to address acid deposition problems in the northeastern United States. While preparing their ozone state implementation plans in the mid-1990s, most of the northeastern states found that they could not reach ozone attainment, even if they "turned off" all manmade pollution sources in their own states. Local controls were not getting the improvements needed. This drew the attention of the U.S. Environmental Protection Agency (EPA), which called for further study that eventually led to the creation of the Ozone Transport Assessment Group (OTAG).

2.0 OTAG Assessments

OTAG was created to "identify and recommend a strategy to reduce transported ozone and its precursors which, in combination with other measures, will enable attainment and maintenance of the national ambient ozone standard in the OTAG region." (OTAG Final Recommendations, 1997). OTAG consisted of 37 states and hundreds of stakeholders, and it conducted the most comprehensive modeling and analysis of ozone transport performed to date.

The OTAG Air Quality Analysis Workgroup concluded that ozone transport may range from zero to over 500 miles, based on direct observations and statistical analyses correlating regional patterns with meteorological factors. The lower end of this range is more likely to be observed in the southern portion of the OTAG modeling domain (the Southern Atlantic and Gulf Coast states), and the higher end of the range is much more common between the Midwest and the northeastern states where the west to east winds are stronger. OTAG modeling results, particularly subregional modeling, supported this scale of transport and showed that emissions in some subregions of the domain, particularly in the Midwest, affect ozone concentrations far downwind in many other areas of the domain.

The Urban Airshed Model (UAM-V) used for the OTAG analyses has been shown to under-predict ozone transport distances, thus the actual upper end of the range of transport is likely to be somewhat greater than 500 miles and the concentrations of transported ozone are likely to be somewhat higher than the modeling shows.

The OTAG assessments clearly confirmed the existence and significance of ozone transport within the OTAG domain, especially within the Northeast. The OTAG Policy Group (OTAG Final Recommendations, 1997) concluded: "Air quality data documents the widespread and pervasive nature of ozone and indicates transport of ozone. Air quality analyses also indicate that ozone aloft is carried over and transported from one day to the next. Generally, the range of transport is longer in the North than in the South."

The OTAG Policy Group reached these conclusions only after a thorough analysis of monitoring station data, weather patterns, and extensive modeling using "state-of-the-science" models. OTAG also used quality assured databases for simulating the physical and chemical processes involved in the formation and transport of ozone and precursor species over multi-day episodes on regional scales. In short, "the OTAG modeling system provides the most complete, scientifically-credible tools and data available for the assessment of interstate transport." (EPA Staff Report, 1997).

A Northeast States for Coordinated Air Use Management (NESCAUM) report on OTAG and air pollution transport (NESCAUM, 1997) concluded the following:

i. Long range transport exists and has been clearly documented in the eastern United States.

ii. Aircraft flights have measured elevated transported ozone readings at night.

iii. Transported ozone from aloft mixes downward to ground level during the morning hours. Downward mixing may occur far downwind of the source regions.

iv. During high ozone events, wind flow (i.e., pollutant transport) patterns over the northern United States are highly aligned from the Midwest to the Northeast.

v. Ozone production on a regional basis is limited by nitrogen oxide (NOx) emissions.

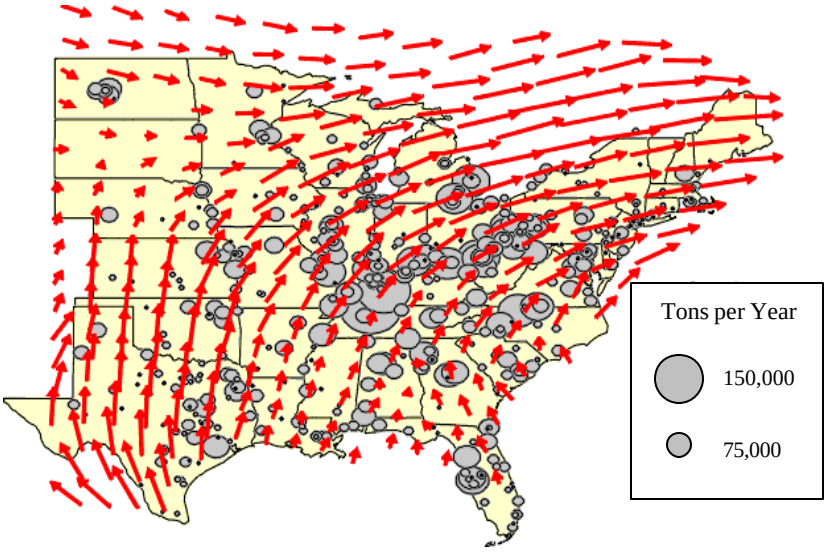
vi. NOx emissions from the industrial Midwest are vastly greater than those from the Northeast, a disparity that will increase as the Northeast continues to reduce emissions under the OTC NOx Memorandum of Understanding (MOU).
(OTAG 1990 inventory data for generating facilities in OTAG Subregions 1-7 shows that New Hampshire emissions comprise less than 1% of the total emissions, and that emissions in the entire OTR comprise only about 29% of the total emissions).

vii. Back trajectory analyses of airmass movements for the most severe ozone days in the eastern United States indicate that pollution was transported to the Northeast from the industrial Midwest. Similar trajectory analyses done for clean air days in the Northeast show airmasses originating in Canada.

viii. Computer modeling performed by OTAG is consistent with measured ozone levels and back trajectory analyses in showing significant impact from transported ozone from the industrial Midwest into the Northeast.

ix. Cost effective NOx reductions can be readily made in the industrial Midwest and these reductions would be especially beneficial to the Northeast.

Figure A.1 - Wind Patterns on High Ozone Days in the Northeast



Arrows show air flow when high ozone levels are present in the Northeast. Also shown are locations and magnitude of NOx emissions from electric generating plants.

Source: NESCAUM, 1997

3.0 Transport Mechanisms

Ozone transport may range from 150 to more than 600 miles in the Northeast, based on direct observations and statistical analyses of regional patterns. For example, multiple analyses of weather patterns, wind speeds and directions, and ozone concentrations suggest statistically significant correlations between upwind and receptor areas 1000 or more kilometers apart; back trajectories calculated from receptor sites in the Northeast during high ozone episodes frequently show aloft airmass travel of 800 to 1,000 km in a 24-hour period (Poirot and Wishinski, 1996; Husar and Renard, 1996; and Porter et al., 1996).

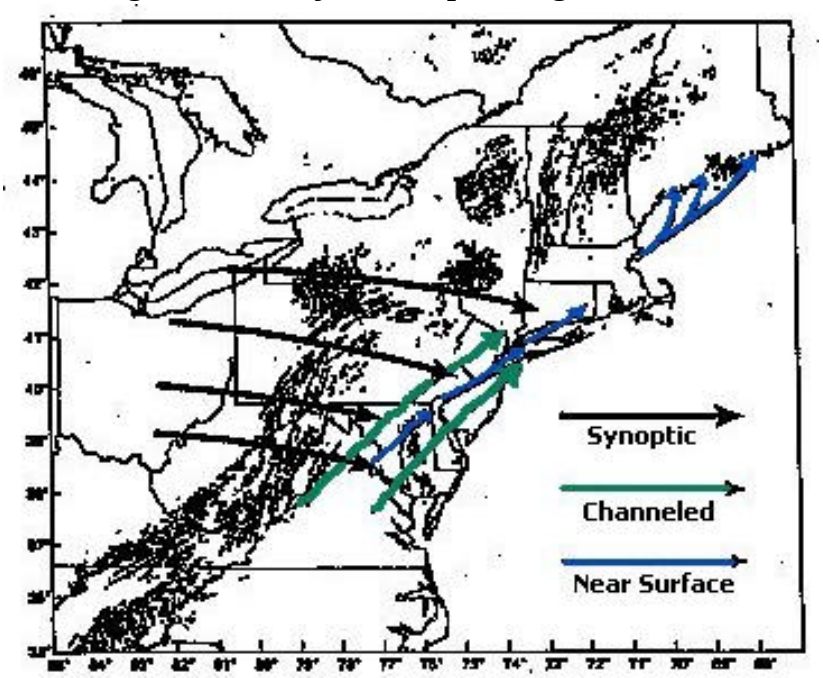
The predominant transport patterns in the Northeast were observed and documented in a 1997 study conducted by the North American Research Strategy for Tropospheric Ozone - Northeast (NARSTO-Northeast) entitled "Initial Results on Transport and Mixing Based on NARSTO-Northeast Data." This study identified three basic flow regimes: Synoptic, Channeled, and Near-Surface.

- The S*ynoptic Flow* is the pattern of airflow at higher elevations (above 2,600 feet). Synoptic flows are unaffected by large-scale frictional ground level objects such as mountains, valleys, and lakes.
- *Channeled Flows* occur at lower elevations (650 to 2,600 feet) where synoptic flow patterns are interrupted by large objects such as mountains, hills, and valleys but are not affected by lower, smaller objects such as trees and buildings.
- *Near-Surface Flows* (below 650 feet) are affected by nearly all surface frictional objects including trees and buildings.

Synoptic flows are generally from west to east, transporting pollution from the Midwest to the Northeast, while channeled flows generally follow the Appalachian Mountains from

southwest to northeast, transporting pollution from the Northeast urban corridor toward northern New England.

Figure A.2 - Major Transport Regimes in the Northeast

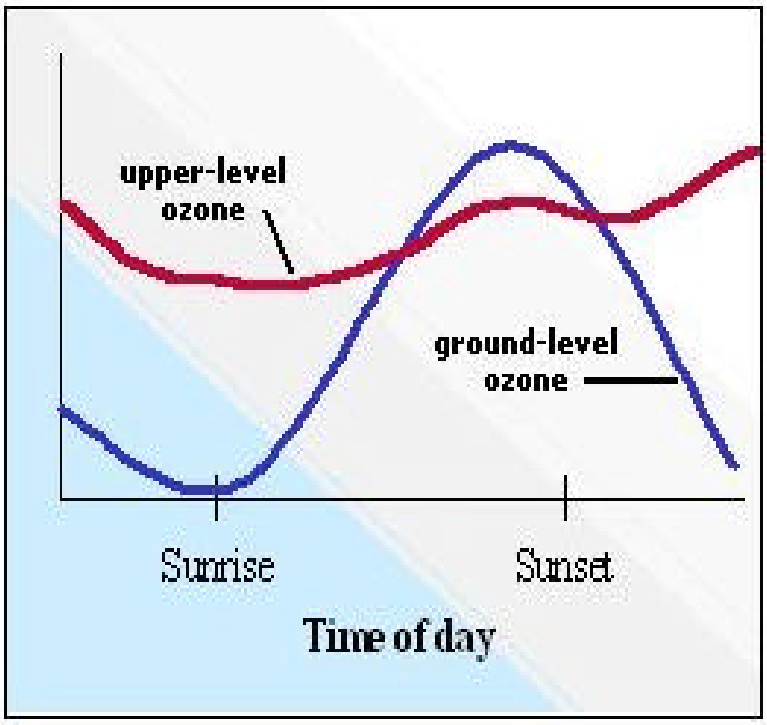


Different types of wind flows common during ozone events.

Source: NARSTO-Northeast

Absent transport, ground-level ozone concentrations increase during sunlight hours as a result of photochemical production and decrease substantially at night when ozone removal exceeds production (also known as diurnal variation or fluctuations within the daily cycle). However, in areas such as New Hampshire which are downwind of large urban regions, ozone concentrations often rise through the evening and/or early morning hours and peak between 6:00 p.m. and 6:00 a.m. due to transport from upwind sources. At higher elevations, concentrations of ozone and ozone precursors may remain high at night, since there is minimal downward mixing of the atmospheric transport layers at night. During daylight hours when solar energy heats the ground, the resulting warm air near the ground begins to rise. Rising air creates an unstable atmospheric situation resulting in the upward and downward mixing of air masses (including ozone transport layers). Thus ground level ozone concentrations typically rise for several hours immediately after sunrise.

Figure A.3 - Typical Day/Night Ozone Cycle at Ground Level and Aloft



Solar ultraviolet energy helps to create ozone, which typically reaches its highest levels in the afternoon hours. At night, there is no ultraviolet sunlight and ground level objects and gases act to remove ozone, resulting in the curve in blue, which represents ozone at ground level. Ozone at higher elevations, conversely, is often not depleted at night and may remain at elevated concentrations throughout the day (red curve).

Source: University of Maryland and NHDES, 2004

3.1 Confirming Observations and Measurements

Episodes of elevated ozone in the New England region generally occur between June and August, during periods of persistent, generally southwesterly surface winds, widespread sunshine, and high temperatures. Typically, the associated meteorological patterns feature an area of high pressure to the south, often centered to the east of the Carolinas, which results in anti-cyclonic (clockwise) circulation over New England. A typical episode begins with elevated ozone levels in southwestern New England. By the second day, ozone levels rise in northern and eastern areas. Ozone levels on any given day tend to peak earliest in southwestern New England, and a pattern of sequentially ordered peaks often appears in northeastern New England where, the farther downwind a site is located, the later in the day peak ozone concentrations are reached. New Hampshire and Maine generally record their highest ozone levels in the late afternoon and evening, with high measured ozone levels occurring sequentially along a monitoring network from Massachusetts through northeastern Maine. For example, the monitors furthest to the northeast, such as Acadia National Park, often record their highest ozone levels during the overnight hours.

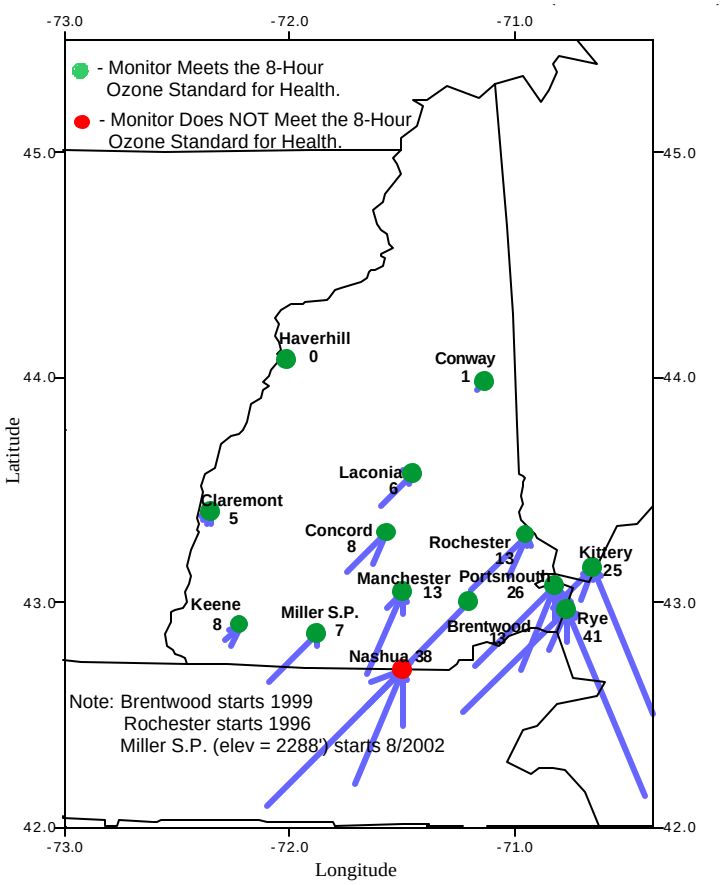
Observations collected by NARSTO-Northeast on July 14, 1995 confirmed elevated levels of ozone extending the length of the Northeast Corridor (Washington, DC, Baltimore, Philadelphia, New York, and Boston regions) during the early morning hours (Blumenthal et al., Feb. 1997). Ozone concentrations in excess of 70 ppb were found at an altitude of 1,600 feet, and since these observations were made before the production of ozone had begun on that day, and given the relatively high wind speeds demonstrated by back trajectories, it is apparent that

this ozone had been transported into Maine and the Northeast Corridor from a considerable distance overnight. This transport mechanism and distance is consistent with that observed by Clark and Ching (1983) in their observations of an ozone plume extending from northern Ohio to the western boundary of the Northeast Corridor over a 26-hour period.

Field measurements during ozone episodes in the late 1980s and early 1990s provide additional evidence of overnight transport via the Midwest to Northeast flow demonstrated by the OTAG analyses described in the previous section. During an episode of elevated ozone concentrations in July, 1988, for example, early morning ozone concentrations ranging from 80 ppb to 120 ppb were recorded at rural mountain top locations and at low elevation sites along the western and southern boundaries of the Ozone Transport Region (OTR), which covers most of the eastern United States. Because ozone does not begin to be produced until later in the morning, these measurements represented ozone that had survived from the previous day. Moreover, in light of the prevailing winds during this episode, these measurements demonstrate that high levels of ozone were transported into the OTR overnight from the West. Relatively small additional amounts of locally produced ozone would have been enough to push these areas over the standard during the day.

The New Hampshire Department of Environmental Services (NHDES) performed studies on what weather conditions have led-up to poor air days in the state. This study can be accessed on the State's website at http://www.des.state.nh.us/ard/ozone/ozone_events.htm. Generally, the majority of the ozone transported into the state comes from the Northeast Corridor. On certain days, the Boston area provides the greatest amount of ozone along the immediate New Hampshire seacoast. The non-New England portion of the corridor provides the majority of the ozone for the remainder of New Hampshire. Air pollution from the Midwest often provides a moderate level of ozone and small particles and on many days provides the large majority of pollution reaching New Hampshire. New Hampshire has its worst air pollution days when low-elevation winds come from the cities to our southwest (Northeast Corridor) and mid-elevation winds come from the Midwest. The haziest days occur when there is a slow airflow from the Midwest. Based on NHDES forecasting expertise and experience, these hazy days correspond to days with high $PM_{2.5}$ concentrations.

Figure A.4 - Number of Days Exceeding the 8-Hour Ozone Standard of 85 Parts per Billion (ppb) and Corresponding Wind Directions (1995 - 2002)



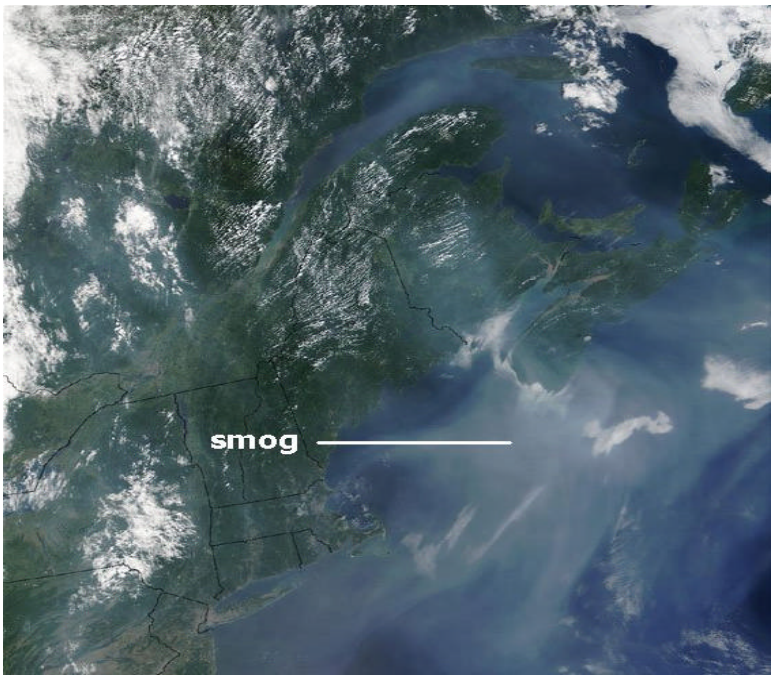
Wind directions at the time unhealthy ozone levels were measured in New Hampshire between 1995 and 2002. There is an overwhelming trend of winds coming into the state from the southwest, with the exception of the seacoast area, which is also affected by sea breezes that bring pollution from the Boston metro area to coastline communities. (Numbers indicate the number of unhealthy air days.)

Source: NHDES, 2003

On a November 4, 2003 flight over the Ohio River Valley, an NHDES official observed a visible smoke stack plume extending over 60 miles without any signs of breaking up. While a visible plume of over 60 miles is somewhat unusual, it does demonstrate how easily the invisible components of air pollution can travel with the wind. Normally a visible plume is bright white and largely caused by condensed water vapor. The water vapor normally evaporates and becomes invisible after traveling a handful of miles downwind. The visible plume seen over the Ohio River Valley started bright white, but quickly became a milky and bluish white, normally caused by very high levels of sulfur dioxide (SO_2) and particles.

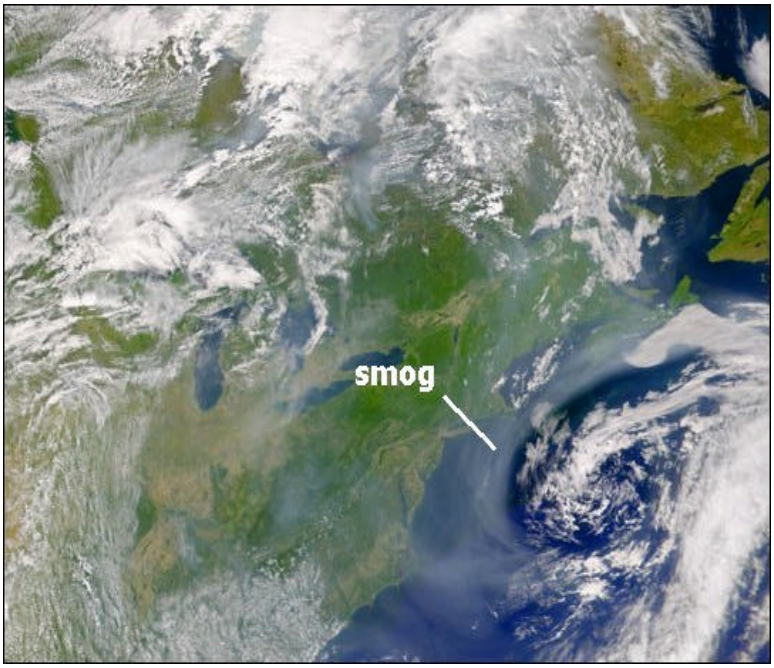
The following satellite photos capture the widespread nature of some air pollution events. Such events are not caused by a single smoke stack, instead they are more dependant on many sources acting together to create the effect. Satellites commonly capture the smoke plumes caused by forest fires and volcanoes, and occasionally can detect broad areas of elevated pollution concentrations.

Figures A.5 and A.6 - Satellite Views of Widespread Smog Events in the Northeast



Satellite photograph of a typical widespread smog event throughout the northeastern states and Canadian Maritime Provinces. Green indicates land, blue is water, bright white is clouds, and milky-white is smog.

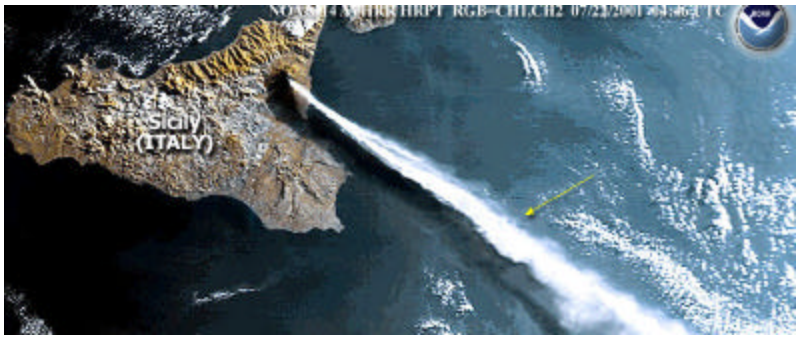
Source: Sea WiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE



Satellite photograph for June 24, 2003 of a widespread smog event throughout the Midwest, Northeast and Canadian Maritime Provinces. Green indicates land, blue is water, bright white is clouds, and milky-white is smog.

Source: Sea WiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE

Figure A.7 - Satellite View of the Mt. Etna Volcano Eruption



Satellite photograph of July 23, 2001 eruption of Mt. Etna (Italy), showing the ash plume extending for hundreds of miles.
Source: National Oceanic and Atmospheric Administration (NOAA)

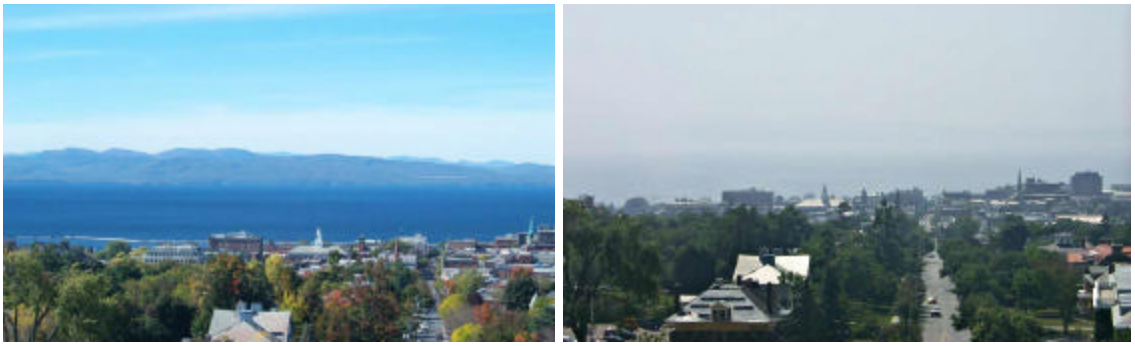
Transport is not restricted to ozone and its precursors. Another class of pollutants, called small particles ($PM_{2.5}$), are hazardous to human health and are often the main cause of reduced visibility in the Northeast, including many natural areas where there are few local sources. Small particles can scatter or absorb light to create a haze that hovers in the air and obstructs the view. The haziest days occur when there is a slow airflow from the Midwest. Based on NHDES forecasting expertise and experience, these hazy days correspond to days with high $PM_{2.5}$ concentrations. The following photographs taken by NESCAUM's CAMNET program (www.hazecam.net) show the dramatic difference between clean air days and those days impacted, in this case, by high levels of sulfate particles (sulfate particle pollution is very efficient at reducing visibility in the Northeast).

Figure A.8 - Comparison Views of Clear and Hazy Days in the Northeast

Photographs of Boston, Massachusetts on a clear day and on a hazy day.

Photographs of Mt. Washington, New Hampshire on a clear day and on a hazy day. Note:View of Mt.Washington on right is completely obscured from only ten miles away.

Photographs of Acadia National Park, Maine on a clear day and on a hazy day.



Photographs of Burlington, Vermont on a clear day and on a hazy day.

Source: www.hazecam.net

3.1.1 High-Elevation Transport

Aircraft Measurements

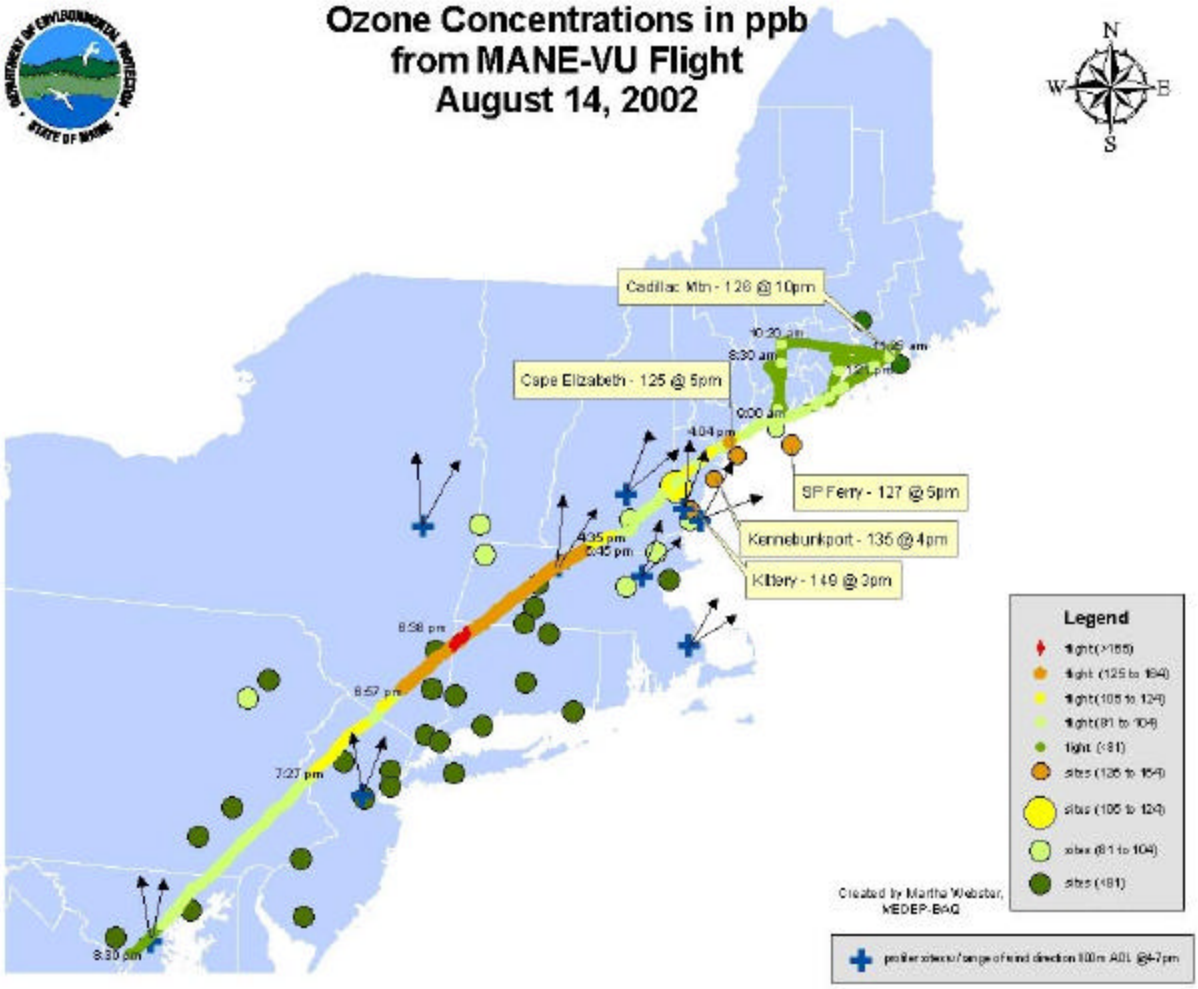
Aircraft measurements by the North American Research Strategy for Tropospheric Ozone-Northeast (NARSTO-Northeast) during the July, 1995 ozone episode also demonstrate the existence of significant transport into and within the region, contributing to exceedances of the ozone standard in Maine (Blumenthal et al., 1997). Several "spiral" flights a few thousand

feet above Poughkeepsie, NY, Gettysburg, PA, and Shenandoah, VA, recorded ozone levels of 100 ppb or greater in the early morning (4 AM) on two days. One aircraft actually recorded an ozone concentration well above 120 ppb at an elevation of approximately 2,600 feet above Poughkeepsie on July 14, 1995, when near-surface ozone measured about 30 ppb. Another flight during the early morning of July 14, 1995, from Virginia to Maine recorded ozone levels in the range of 70 ppb to 100 ppb at an elevation of 1,600 feet throughout the Northeast corridor.

These elevated ozone concentrations measured in the early morning at high elevations suggest that the ozone and its precursors originated during the active times of the previous day or days and traveled up and away from the source locations. Spiral flights in the afternoon over the same three cities measured uniform ozone levels from ground level to 2,600 feet, showing that the air had become well mixed during the day and had thus brought transported ozone aloft down to the surface. A second flight along the length of the entire corridor showed that ozone levels at 1,600 feet had risen well above 120 ppb in the Baltimore-Washington and New York metropolitan areas. Being well above the ground, this ozone was presumably destined to be transported further downwind overnight.

On behalf of the Mid-Atlantic Northeast Visibility Union (MANE-VU), additional aircraft measurements were taken to track a regional haze event in the Northeast in August of 2002 (see Figure A.9). The aircraft measured light scattering from particles as well as ozone. Like the earlier NARSTO-Northeast measurements, the MANE-VU study found high levels of ozone aloft which were blowing toward the northeastern states. In most cases, the ozone measured aloft exceeded measurements collected at ground level, indicating that the ground-level ozone was not all created locally. It is also noteworthy that the preliminary measurements collected above Baltimore, Maryland were already rich in ozone, suggesting that a large amount of the pollutant was blowing into the region from upwind areas. Ozone aloft is depleted much more slowly than ozone at surface level, which comes into contact with various surfaces and obstructions. This means that, once ozone is present at high elevations, it becomes more likely to travel long distances downwind without breaking down.

Figure A.9 - Aircraft Ozone Observations in the Northeast



Ozone measurements from aircraft observations compared to ground based measurements. Arrows indicate the range of wind directions at 800 meters above the surface.
Source: Maine Department of Environmental Protection

Mountaintop Monitoring – Mt. Washington, New Hampshire

Mt. Washington in Pinkham Notch, New Hampshire, is tall enough (6,288 feet) to reach well up into the upper ozone transport layers with minimal obstruction by other terrain features. Ozone levels recorded at the summit of Mt. Washington mirror NARSTO findings, showing consistently elevated levels of ozone with little diurnal variation during most episodes which is clear evidence of long range transport. As further evidence of long range transport, the Camp Dodge monitor (2,400 feet), located at the base of Mt. Washington, usually records lower ozone concentrations than those seen contemporaneously at the summit. Both monitors have no major NOx sources within 75 miles and no major sources upwind in the direction of prevailing winds for approximately 150 miles. Transport from more distant upwind sources is the primary source of ozone monitored at these sites.

Since the summit of Mt. Washington is high enough to be exposed to high elevation transport (synoptic flows), downward mixing is not a factor in creating the peak ozone values it experiences. In fact, transport time from upwind source areas appears to be the single largest factor in determining the time at which the maximum ozone level occurs at the summit. Daily maximum ozone levels at Camp Dodge are dependent on inversion breakup caused by downward mixing from upper transport elevations, and thus are typically recorded during the afternoon hours. On the contrary, maximum ozone levels at the summit occur most often during the overnight hours, when no ozone is produced locally. The percent share of daily one-hour ozone maxima, which occur during daylight heating hours and outside of daylight heating hours on the summit of Mt. Washington and at Camp Dodge, is listed in Table A.1.

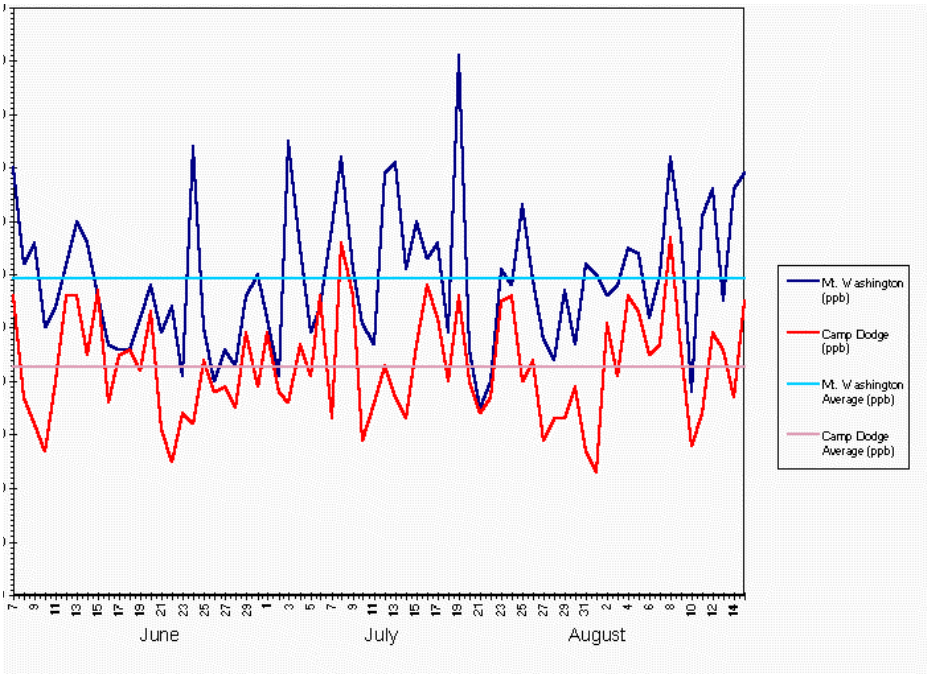
Table A.1 - Night and Daytime Patterns of Ozone at the Base and Summit of Mt. Washington

Mt. Washington Monitor Location	Percent of Hourly Maxima During Daylight Hours (9 a.m. to 5 p.m.)	Percent of Hourly Maxima During Overnight Hours (6 p.m. to 8 a.m.)
Summit	18%	82%
Base (Camp Dodge)	80%	20%

Note: Daylight heating hours are hours of the day when solar energy drives vertical mixing of transport layers

The difference in ozone concentrations at the summit and base can also be seen when looking at plots of maximum ozone levels at each site. The graph shown in Figure A.10 is typical of summertime ozone at Mt. Washington.

Figure A.10 - Comparison of Hourly and Summer Average Ozone Concentrations at the Base and Summit of Mt. Washington, 1996



Relative comparison of mountaintop (elevation 6,288 feet) hourly ozone (blue line) with mountain base (elevation around 2,000 feet) hourly ozone (red line). Often the ozone concentration is higher at the summit due to pollution transport from distant sources. On occasion the ozone at the base is driven by downward mixing from the upper transport layers during the day. Source: NHDES (Data: Appalachian Mountain Club)

Mountaintop Monitoring – Pack Monadnock, Miller State Park, New Hampshire

Another mountaintop air pollution monitor was established in 2002 in Miller State Park at the summit of Pack Monadnock Mountain in Peterborough, New Hampshire (elevation 2,288 feet). The mountain is located in the southwestern portion of New Hampshire in an ideal location to track air pollution transport into the state. The monitor is located only a short distance from the heavily visited and hiked Mt. Monadnock. The early findings from this monitor are similar to those of Mt. Washington in that when an ozone or $PM_{2.5}$ episode begins to build into the region, it is detected at higher elevations first where the stronger transport currents are located. The new Miller State Park monitor has been useful in tracking air pollution events entering the populated Merrimack Valley area (Nashua, Manchester, and Concord).

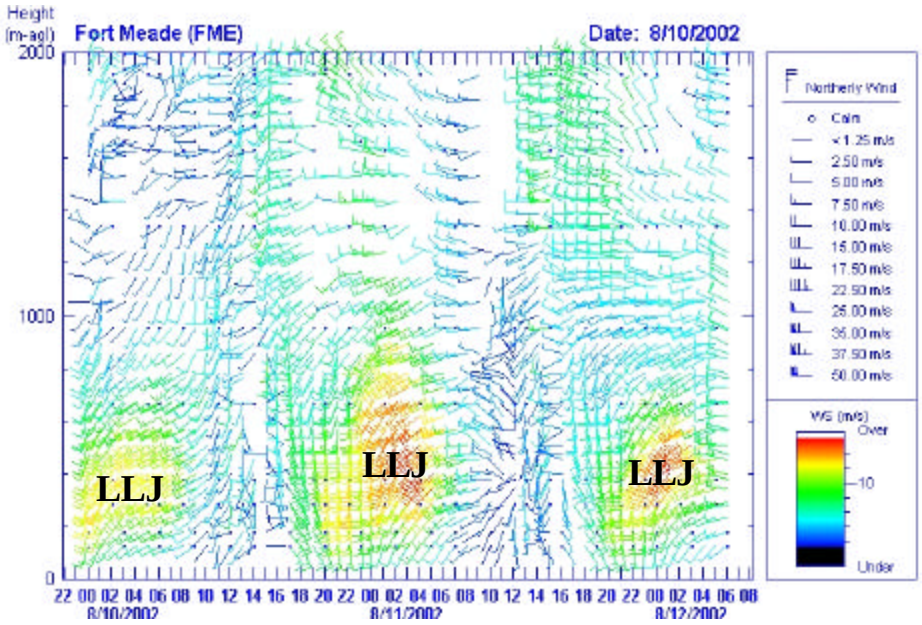
3.1.2 Mid-Elevation Transport

Mid-elevation transport is usually dominated by the effects of large topographical features, such as mountains, which redirect airflows and cause a channeling of the wind. In the Northeast, channeled airflows may occur on either side (east or west) of the Appalachian Mountain range and also between the subranges that comprise the Appalachian chain. Unhealthy air quality can be present on one side of a mountain while just a few miles away on the other

side, the air quality is substantially cleaner. This mid-layer is generally heavily influenced by the airshed layers above and below that mix polluted, or clean air into it. Pollutants can also be injected directly into this layer by some of the very tall smoke stacks (around 1,000 feet tall) commonly found in the Midwest.

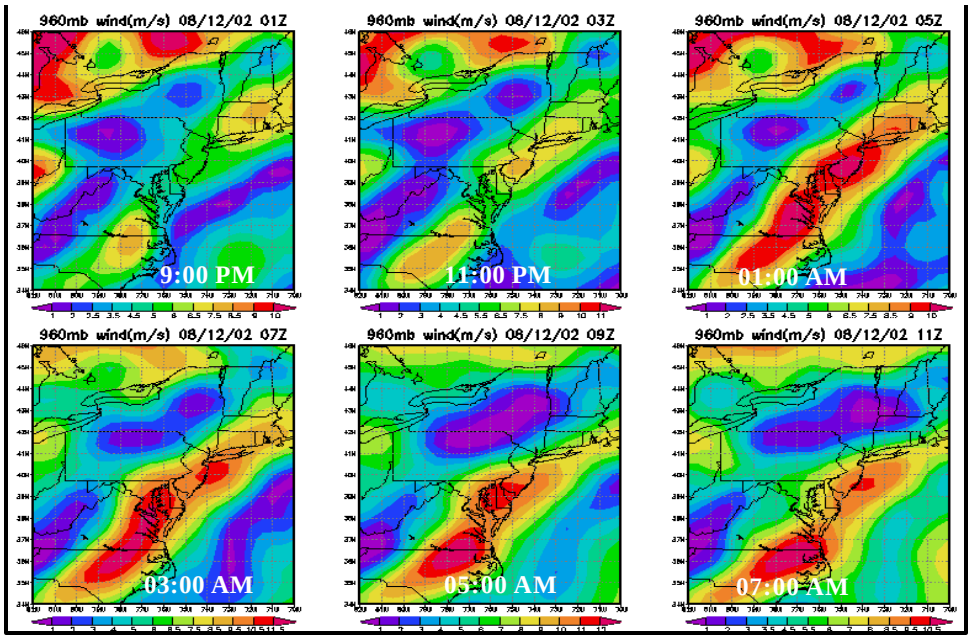
Mid-level transport is often affected by a phenomenon known as the low-level jet (LLJ). It is called "low-level" because it is lower in altitude relative to the well know Jet Stream, a high elevation airflow that drives the movement of weather systems around the world. Recent advances in remote sensing instruments (i.e., radar profilers) have allowed the LLJ phenomena to be observed. During the overnight and early morning hours, a LLJ frequently forms just east of the Appalachian Mountains. Once formed, the LLJ is a strong west to southwest wind flow that develops at low altitudes just above the nocturnal boundary layer. These winds typically reach speeds of 40-50 mph and are located at approximately 1,000 to 2,000 feet above the ground. Figures A.11 and A.12 depict the LLJ observed during an August, 2002 ozone event.

Figure A.11 - Wind Profiler Observations of the Low-Level Jet During a High Ozone Episode



Plot of low-level winds from the Fort Meade, Maryland wind profiler. A low-level jet developed during three consecutive days where ozone levels were high in the area. Areas of high wind speed develop overnight and are associated with wind direction shifts (identified in yellow, orange and red).
Source: University of Maryland, 2002

Figure A.12 - Computer Model Illustration of the Low-Level Jet in the Northeast



The low-level jet (shown by red, orange, and yellow) normally sets up along the eastern side of the Appalachian Mountains and blows from southwest to northeast.
Source: University of Maryland, 2002

3.1.3 Low-Elevation Transport

A number of one-day and multi-day low-elevation transport mechanisms have been observed along the northeastern coastal plain. Blumenthal et al., (1997) described several transport mechanisms, including near-surface flows that act within a thousand feet of the ground and are capable of transporting ozone and its precursors along the urban corridor as far as 160 miles during the daylight hours. Near surface flows are especially useful in explaining the transport and presence of the elevated ozone concentrations monitored aboard the MS Scotia Prince ferry in the Gulf of Maine (Portland, Maine ferry to Yarmouth, Nova Scotia, Canada).

Other transport mechanisms, including boundary layer synoptic (upper-level) flows and channeled (mid-level) nighttime flows are capable of transporting ozone and precursors as far as 600 km in a 24-hour period and are responsible for longer range transport from the south and west (Blumenthal et al., 1997).

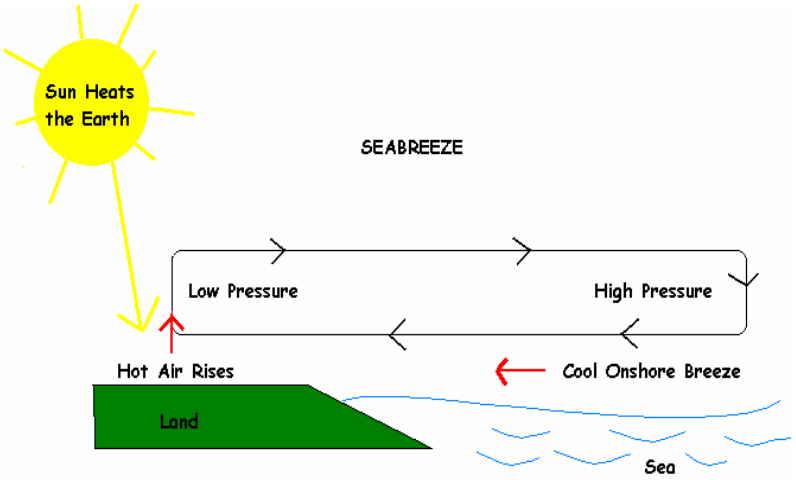
Residence time is defined as the amount of time that a pollutant stays in the air. Residence time analysis (Wishinski and Poirot, 1996) is a technique whereby the spatial characteristics of long-term trajectory climatology can be analyzed by keeping track of the residence time (in hours) for selected back trajectories. This type of analysis was done for several New England sites during the summers from 1989 through 1995. Back trajectories from Port Clyde, Maine, show that on days that Maine exceeds the ozone National Ambient Air Quality Standard (NAAQS), the wind is invariably from the south and west. These trajectories

also show that the Northeast Corridor is principally responsible for nonattainment in New Hampshire and Maine, with areas to the south and west of the Corridor having lesser, but still significant impacts.

Sea Breeze

The Atlantic Ocean produces changes in wind directions and wind speeds along the shoreline, especially in New England. While most inland areas experience regional wind patterns with only small variations due to terrain features and other frictional effects, coastal locations are far more variable. Sea breezes develop during the heating of the day when the ground heats up, warming the onshore air mass. This air mass then rises, causing cooler air near the surface to flow in from over the ocean. Sea breezes are actually a subset of the NARSTO-Northeast near-surface flows that are driven by temperature differences between land and water. These temperature differences also affect changes in mixing heights. Daytime sea breezes flow from the relatively cool waters of the ocean towards the coast, and diminish over a short distance due to mixing with regional wind patterns persisting further inland and with diurnal mixing. Such sea breezes are the primary reason why high ozone concentrations occur along the New Hampshire coast, while substantially lower concentrations are recorded just a few miles further inland.

Figure A.13 - How a Sea Breeze Develops



A sea breeze is developed through the temperature differences between the ground and the water. As the sun warms the ground, it begins a cycle by causing the air to rise. This air cools as it moves over the water, sinks and then blows back towards the shore. Source: NHDES, 2003

The afternoon sea breeze shifts the wind direction to the south and east, bringing ozone from over the ocean onshore. As documented by NHDES and the Maine Department of Environmental Protection (MEDEP), sea breezes develop suddenly, shifting the wind from the northwest to the south or southeast, and driving ozone concentrations sharply upward. The offshore ozone blown in by sea breezes appears to originate from precursors emitted in the metropolitan Boston area.

Offshore Transport

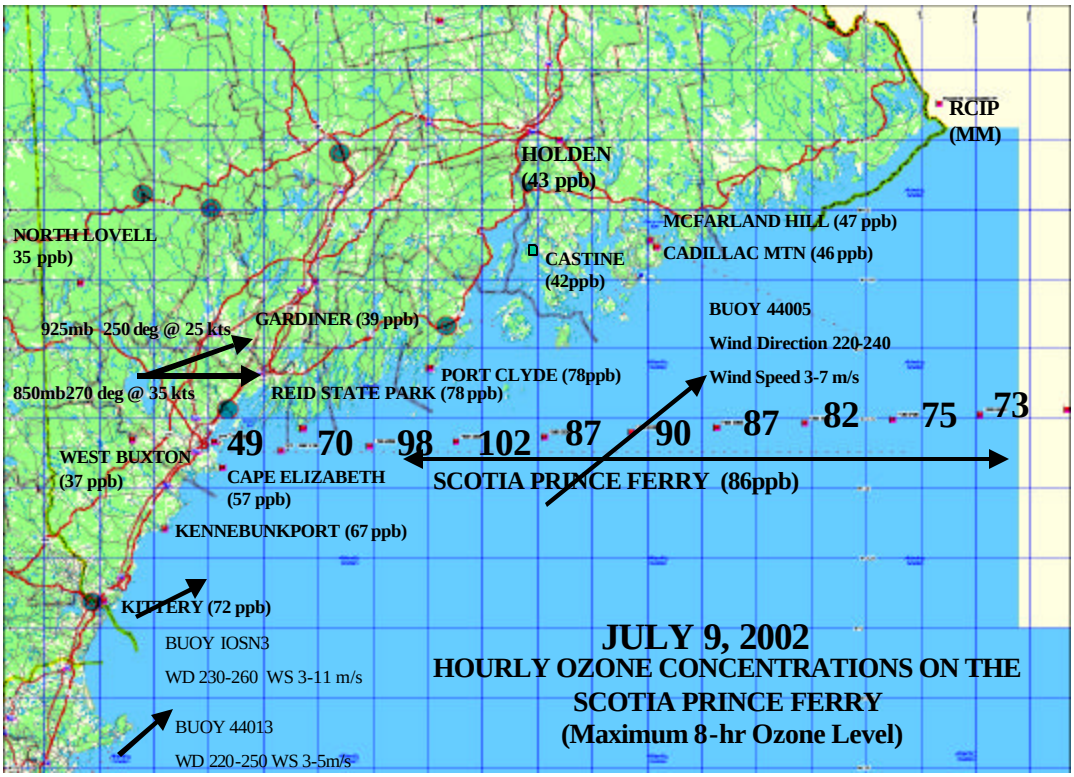
Offshore, just beyond the strongest coastal sea breezes, larger scale wind fields develop that may differ in direction from the inland regional wind pattern. Lower mixing heights, differing temperature gradients, and lower frictional effects cause this directional difference. Off the New Hampshire and Maine coasts, it is not uncommon for the over-water wind field to come from the south, while the inland regional wind field is more from the southwest. This pattern allows transport of the ozone plume from the metropolitan Boston area to travel over the Gulf of Maine to the New Hampshire coast, even when inland wind observations suggest this should not be happening.

The North Atlantic Regional Experiment (NARE) measured surface level ozone and precursor concentrations at both coastal and offshore locations in the Gulf of Maine during August and September of 1993 (Ray et al., 1996). The researchers observed ozone plumes in the Gulf of Maine ranging in width from 55 km to 93 km, and extending the entire length of the New Hampshire and Maine coastlines. The timing of the observed peak ozone concentrations, the presence of elevated ozone levels only along the coast, and low total reactive nitrogen oxides (NO_y) concentrations all suggest that urban plumes transported over the Gulf of Maine are brought inland by sea breezes to the coastal regions, and that regional control strategies will be needed to reduce ozone concentrations along the coast.

Recent photochemical modeling utilizing the CALGRID model (Earth Tech, 1997) serves to confirm the presence of an urban plume moving northeastward over the Gulf of Maine, where it is then carried onshore by afternoon sea breezes to the coast.

Along the New Hampshire and Maine coastlines, ozone levels have not been observed to exceed the NAAQS unless there is at least a moderate westerly to southwesterly wind at the surface early in the day. Typical ozone episodes are characterized by the concentration of transported ozone and precursors in the Gulf of Maine during the morning and midday hours, with afternoon sea breezes bringing high concentrations of ozone ashore in the afternoon and evening. Monitored ozone concentration data and measured wind vectors show ozone exceedances in Maine to be the direct result of a large mass of both ozone and un-reacted ozone precursors being transported into the Gulf of Maine from areas to the south and west. Here, these precursors react and are then transported onto the shore, a conclusion supported by data collected by monitors on both the MS Scotia Prince ferry (see Figure A.14 below) in the Gulf of Maine and on land-based monitors that show significantly decreased levels of ozone at inland sites.

Figure A.14 - Offshore Ozone Measurements from the MS Scotia Prince Ferry



The MS Scotia Prince ferry is a scheduled passenger and vehicle ferry that runs between Portland, Maine and Yarmouth, Nova Scotia, Canada (route indicated by red dots). This ferry has an ozone monitor that tracks air pollution levels during its journey between ports. The ferry often identifies distinct air pollution areas or plumes offshore over the Gulf of Maine.
Source: Maine Department of Environmental Protection and AIRS

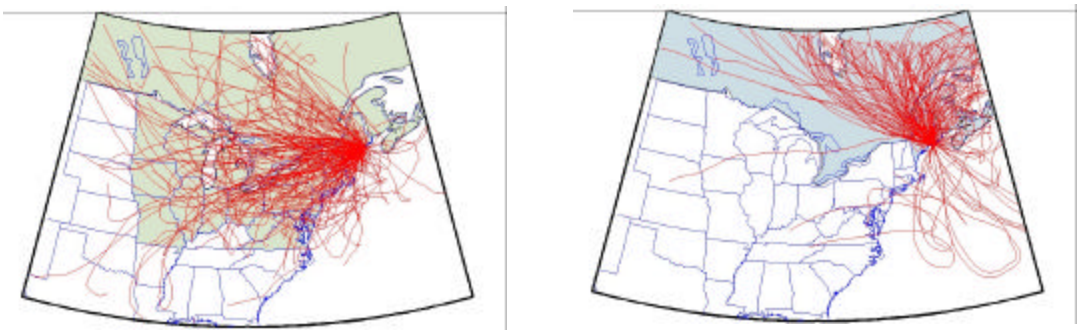
Ozone air quality monitors within the State of Maine also confirm the presence and significance of transported ozone and its precursors. The ozone monitoring network in Maine extends along the coast from the Photochemical Assessment Monitoring Station (PAMS) located in Kittery, Maine (operated by NHDES) to as far north as Bar Harbor. Maximum ozone concentrations along the Maine coast almost always follow a sequential pattern, with the most southerly sites monitoring daily ozone maximums in the mid to late afternoon, and downwind sites experiencing maximum readings later in the day and into the evening hours. Data from the Kittery site is especially illustrative in that it represents ozone concentrations at the Maine/New Hampshire border and is an objective measure of transport from areas immediately to the south. Elevated ozone concentrations at this site can only be the result of interstate transport**.**

3.2 Confirming Modeling and Assessments

3.2.1 Back-Tracking Air Pollution to the Source Area

Back trajectory frequency analyses presented by Poirot and others (Poirot et al., 2002) to OTAG concluded that the cleanest airmasses originate in Canada and northern New England (Maine, New Hampshire, Vermont, and northeastern New York). The most polluted airmasses originate in a region that is approximately outlined by Chicago, St. Louis, Memphis, Washington, DC, and Boston. This region includes the industrial Midwest and most of the Ozone Transport Region. Figure A.15 shows these back trajectories for a site in northern Maine on both clean and hazy days.

Figure A.15 - Wind Trajectories on Hazy and Clean Days at Acadia National Park in Maine

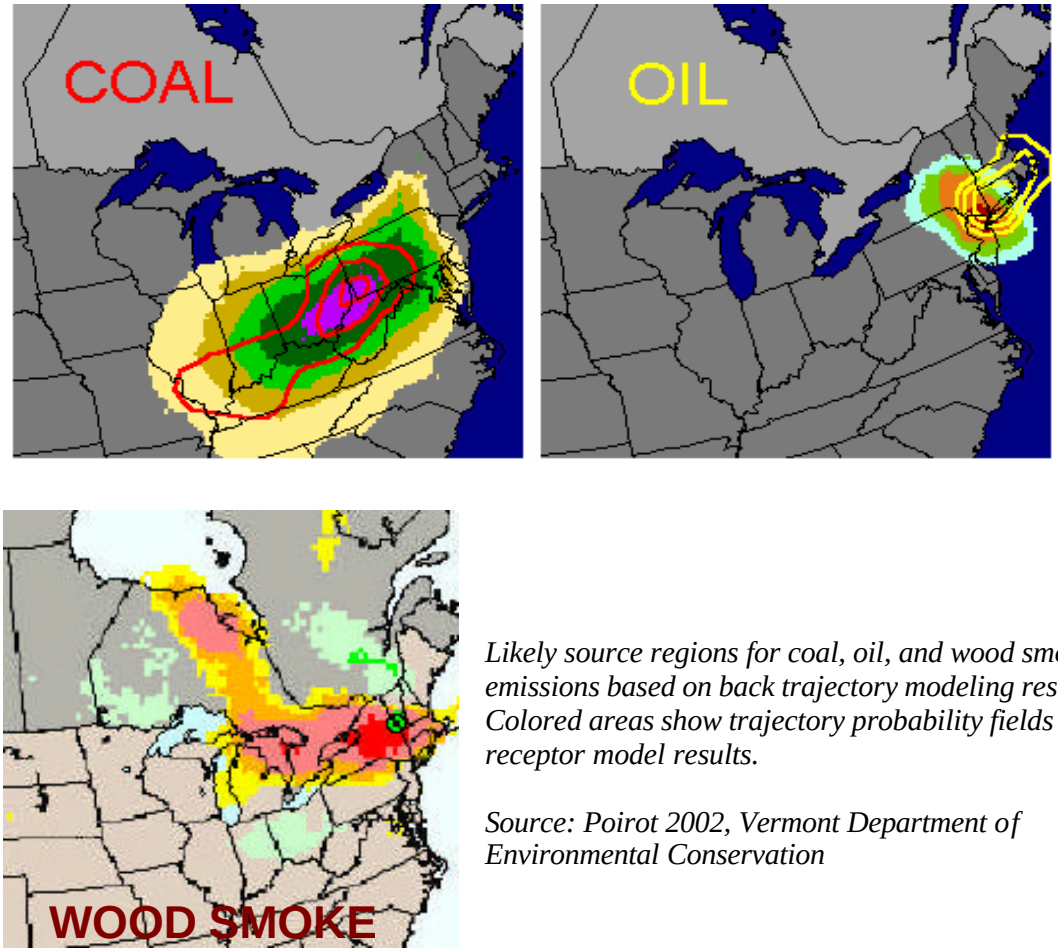


20% Worst Visibility (Hazy) Days 20% Best Visibility (Clean) Days

HYSPLIT Back Trajectories for Acadia National Park 1997 to 1999. Red lines indicate where the wind came from during days of bad and good visibility.
Source: NESCAUM

Studies by Poirot (Poirot et al., 2002) determined the probable emission source areas during periods of high levels of air pollution in Lye Brook, Vermont and Brigantine, New Jersey. These studies considered back trajectories during periods when certain species of small particles and ozone were measured to be at elevated levels. Some of the results of these studies are shown in Figure A.16, which shows probable source regions for coal, oil and wood smoke emissions based on trajectory analyses. Figure A.17 shows the location and magnitude of SO_2 emissions from coal and oil burning sources based on EPA data. The locations of the large SO_2 emission sources correlate well with the source regions identified by the back trajectory modeling, showing that most SO_2 and sulfate received in the Northeast comes from urban areas to the south and industrial regions in the Midwest. Wood smoke in the Northeast is largely a product of Canadian forest fires and New England wood stoves, fireplaces, and open burning.

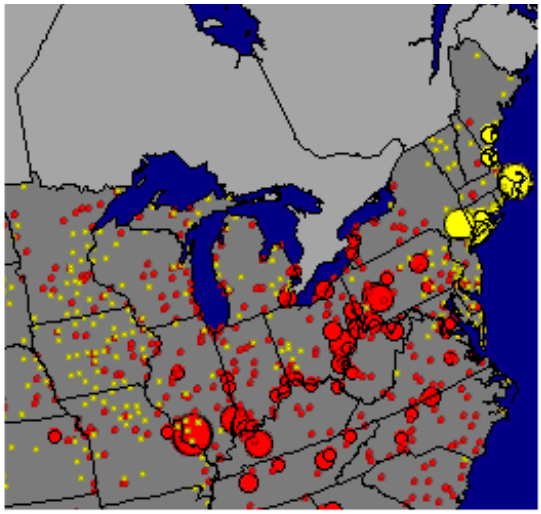
Figure A.16 - Trajectory and Probability Analyses Results During High Pollution Episodes in the Northeast



Likely source regions for coal, oil, and wood smoke emissions based on back trajectory modeling results. Colored areas show trajectory probability fields from receptor model results.

Source: Poirot 2002, Vermont Department of Environmental Conservation

Figure A.17 – Sulfur Dioxide Emissions from Coal and Oil Burning Sources, 1998



Location and magnitude of sulfur dioxide emissions from coal (red) and from oil (yellow). Relative emissions magnitude is indicated by size of the circle. Oil emissions are indicated ten times larger than actual.

Source: EPA EGRID database, 1998

A report presented to OTAG by Husar and Renard, "Ozone as a Function of Local Wind Direction and Wind Speed: Evidence of Local and Regional Transport, (1997)," which supports the OTAG Air Quality Analysis (AQA) group recommendations, states:

> *"The Boston, MA metropolitan area shows virtually no dependence of ozone concentration on wind speed, except during northeasterly winds. The lack of wind speed dependence clearly indicates that the average concentration in Boston is dominated by transport and that the local contributions to the average are virtually undetectable. Directionally, southwesterly winds are the highest at 70 ppb, and northeasterly transport brings lowest ozone concentrations at about 45 ppb."*

If ozone concentrations in the metropolitan Boston area are dominated by transport, then it follows that the impact of transport is even more dominant in areas that are proximate to, downwind of, and which have lower emissions than metropolitan Boston itself, such as New Hampshire.

3.2.2 Ozone Contribution Analyses Based on OTAG Data (Culpability Analysis)

NHDES conducted a thorough analysis of grid cell-by-grid cell, hour-by-hour data for the approximate 35,000 grid cells used for OTAG's modeling of the 1995 ozone episode ("Apportioning Relative Ozone Culpability" and "Assessment and Apportionment of Ozone Culpability"). Through this analysis, an "ozone response curve" was developed which correlates ozone impacts directly with NOx emission levels in the various OTAG subregions.

"Culpability analysis" uses this ozone response curve to assign relative responsibility to upwind source regions for downwind transported ozone concentrations. New Hampshire believes that culpability analysis provides the best available evidence that non-New Hampshire sources, including electric generating facilities in the Midwest, contribute significantly to the transport of ozone and ozone precursors to New Hampshire.

Culpability analysis using OTAG subregional zero-out run data was performed for the July 10-18, 1995 ozone episode, which was a period of several exceedances of the ozone NAAQS in New Hampshire. It is clear from this analysis that ozone and its precursors can contribute to downwind ozone levels over distances as far as 1,000 miles from emission sources. In addition, the analysis shows that the entire OTAG domain is subject to regional ozone transport to a significant extent, ranging from 20 percent to over 70 percent in some areas. It is noteworthy that at least 20 percent of the ozone in each OTAG subregion appears to be produced outside of the subregion. In other words, to a greater or lesser extent, all OTAG subregions both contribute to and are recipients of significant regional ozone transport.

The results of New Hampshire's culpability analysis for the fine grid OTAG subregions which contribute more than 5 percent to New Hampshire's ozone concentrations are shown in Table A.2.

Table A.2 - Culpability for Ozone in New Hampshire According to the New Hampshire Culpability Study During the OTAG Assessments

General Description of OTAG Subregion	Culpability from OTAG Subregion to New Hampshire
Southern half of Wisconsin, Northern half of Illinois, parts of Indiana, Iowa, Michigan.	5 to 10%
Southern half of Michigan, Northern half of Ohio, parts of Indiana.	5 to 20%
Most of Pennsylvania, Western half of New York.	30 to 50%
All of New Jersey, Delaware, Connecticut, parts of eastern Pennsylvania, Metropolitan New York City.	10 to 30%
Southern half of Illinois, Eastern Missouri, Western Kentucky, Southern Indiana.	Up to 10%
Southern half of Ohio, Eastern half of Kentucky, Western half of West Virginia, parts of Indiana and Virginia.	Up to 10%
All of Maryland, Most of Virginia, Eastern half of West Virginia.	Up to 10%
Massachusetts, Vermont, New Hampshire, and Maine	5 to 50%

Source: NHDES, 1997

OTAG data suggests that over distances of approximately 100 to 150 miles, concentrations of ozone in the Northeast are reduced by half (i.e., a "half-distance" applies which is similar to the concept of "half-life" in radioactivity). Using this approach, NHDES has determined that ozone and NOx can be transported more than 600 miles while retaining more than 6 percent of their ozone forming capability. Such contributions from distant sources could easily move New Hampshire from attainment to nonattainment. For example, generating facilities located 750 miles upwind and emitting 320 tons of NOx per day can provide equivalent pollutant impact to facilities emitting ten tons of NOx per day located less than 150 miles upwind of New Hampshire.

Applying the "half-distance" concept to generating facility emissions focuses primarily on a large number of nearby sources or groups of sources, adding more distant ones as they exceed greater "half-distance" emission thresholds. For each concentric "half-distance" one moves upwind, sources or groups of sources of twice the size have the same downwind ozone impact. This dynamic is illustrated in Table A.3. While this approach is based on generating facilities which emit ten tons or more of NOx per day, the collective transport impact of facilities with lesser emissions should not be ignored.

Table A.3 - Ozone Half-Distance Range Estimates Based on the OTAG Modeling Assessments

Half-Distance Range (miles)	Facility NOx Emissions (tons/day)
0-150	10
150-300	20
300-450	40
450-600	80
600-750	160
750-900	320

3.2.3 New Hampshire Photochemical Modeling

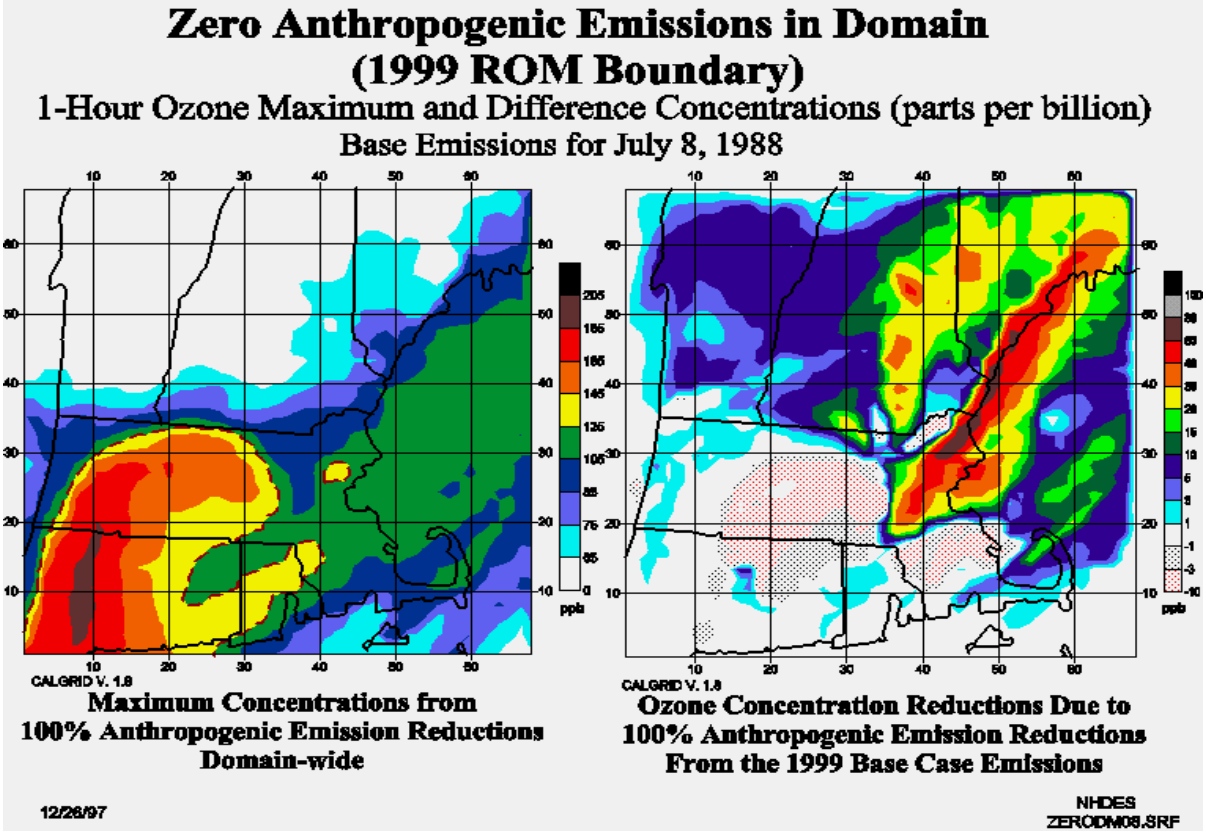
NHDES performed one-hour ozone photochemical modeling with the Massachusetts Department of Environmental Protection (MADEP) and filed the most recent Progress Report for the New England Domain Ozone Attainment Demonstration (Progress Report) in February of 1997. As recommended by EPA, the Progress Report employed the Urban Airshed Model (UAM) to assess the effect of various control strategies on attainment. The Progress Report modeled two 1988 episode days, July 8 and July 11, for the purposes of evaluating model performance, preliminary testing strategies, and determining the impact of transport into the domain. During the July 8 episode, exceedances were recorded in two ozone plumes, one large plume stretching from the southwest corner of the domain north through Connecticut and along the Connecticut River Valley in Massachusetts, and one plume running from Boston, Massachusetts north along the coast of New Hampshire and Maine. In the July 11 episode, a large plume stretched from the southwest corner of the domain east through Connecticut, Rhode Island, and southeastern Massachusetts, with a second plume again extending from Boston north along the coast.

With respect to transport, the model predicted that elimination of all manmade emissions in the domain would eliminate the smaller coastal plume from Boston north. Less drastic strategies were less effective. Rate of progress controls through 1999 reduced, but did not eliminate the exceedances for July 8 in either the main plume or the north coastal plume. Recent photochemical modeling utilizing the CALGRID model (Earth Tech, 1997) serves to confirm the presence of an urban plume moving northeastward over the Gulf of Maine, where it is then carried by afternoon sea breezes to the New Hampshire and Maine coast.

Modeling for the New Hampshire Ozone Attainment demonstration for the one-hour NAAQS (http://www.des.state.nh.us/ard/sip.htm) found that the major pollution sources in the region are located in the Boston area. When these emissions were theoretically eliminated, there was still a large amount of ozone transport into the New England region (see Figures A.18 and A.19). Many areas in southern New Hampshire were already between 80 percent and 90 percent of the one-hour ozone health standard, without adding any emissions from anywhere else in New England. Thus, the air was so dirty when it came into the area that it would take very little

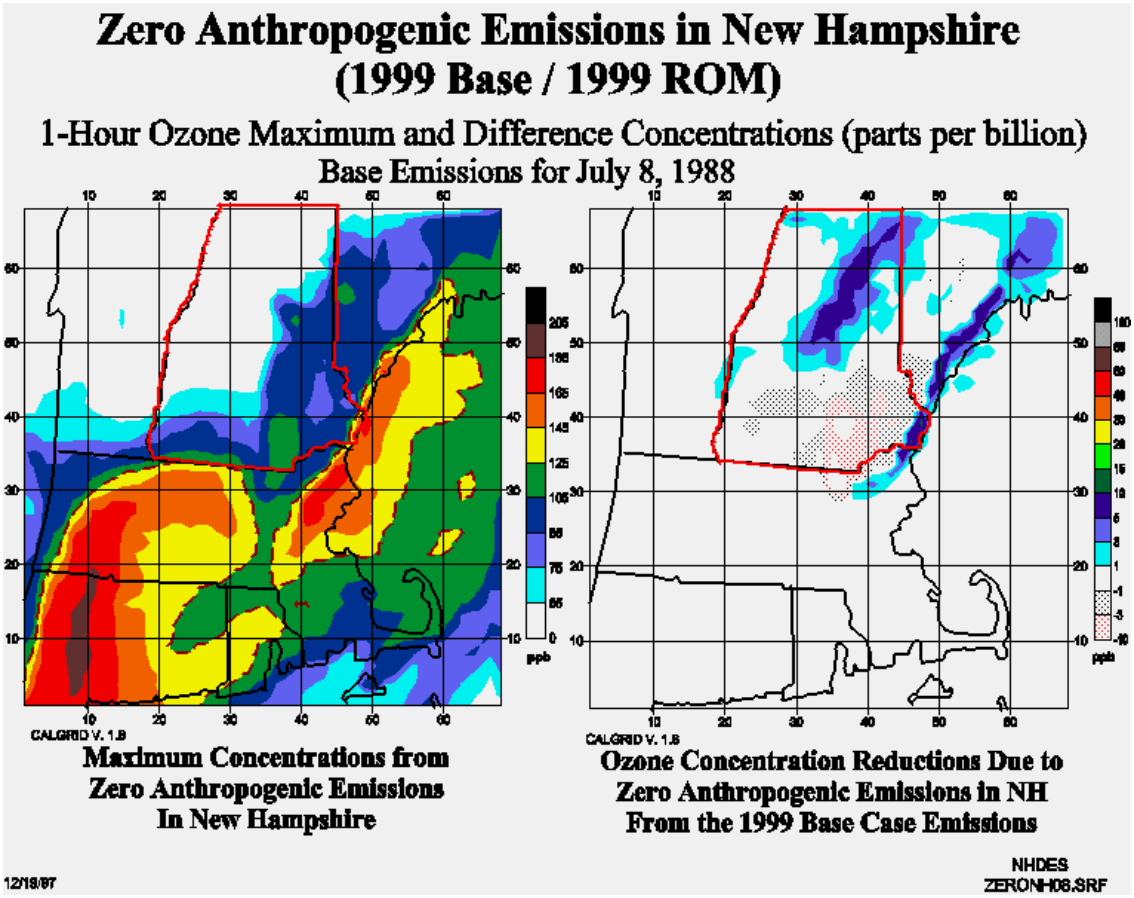
additional emissions to exceed the standard. This modeling further showed that 94 percent to 100 percent of the ozone measured in New Hampshire comes from out-of-state sources. The exact sources vary from day-to-day depending on wind patterns. The analysis also showed that eliminating all manmade sources within New Hampshire would result in only minimal air quality improvement. More recent photochemical modeling performed by the NHDES has refined this transport to 92 percent to100 percent.

Figure A.18 - Photochemical Modeling Case Where All Manmade Pollution Emissions Were Theoretically Eliminated Within New England



***Left side**: Modeled ozone levels in a hypothetical case where all manmade air pollution emissions are eliminated in the area shown in the map. High levels still exist in the area (shown by green, yellow, orange, red and brown).*
***Right side**: Modeled ozone reductions under the same case. Large reductions (green, yellow, orange, red, and brown) are made in areas downwind of metropolitan Boston where emission density is the highest within the area shown by the map.*
Source: NHDES, 1997

Figure A.19 - Photochemical Modeling Case Where All Manmade Pollution Emissions Were Theoretically Eliminated Within New Hampshire



***Left side**: Modeled ozone levels in a hypothetical case where all manmade air pollution emissions are eliminated in New Hampshire. High levels still exist in the area (shown by green, yellow, orange, red and brown).*

***Right side**: Modeled ozone reductions under the same case. Only modest ozone improvements (shades of blue) are made in areas downwind of the Merrimack River Valley and the seacoast areas where the emissions within the State are the highest (including areas along Interstates I-93 and I-95).*

Source: NHDES, 1997

TECHNICAL ATTACHMENT B
$PM_{2.5}$ HEALTH VALUATION CALCULATIONS

Table B.1 summarizes the results of the calculations used to estimate health risk valuation for transport of $PM_{2.5}$ into New Hampshire. NHDES used previously-released health impacts from power plant emissions, extrapolated the data statewide and estimated the total cost to the state. The full methodology and explanation for the associated calculations follows the table.

Table B.1 - Projected Risk Values Due to $PM_{2.5}$ Transport Into New Hampshire (1999$)

Adverse Effect	Incidents from Power Plants		Total New Hampshire Estimated Incidences [3]	Mean 1999$ Valuation per Incidence (Abt range) [4]	Total New Hampshire Valuation (1999$) [5]
	Abt Boston CMSA Incidences [1]	New Hampshire CMSA Incidences [2]			
Premature Mortality	454	60	123	$6,120,000 (3.8-8.9 million)	$753,472,724
Chronic Bronchitis	302	40	82	$331,000 (57,000-1,275,000)	$27,107,858
Acute Bronchitis	839	111	228	$57 (17-98)	$13,055
Hospital Admissions	320	42	87	$14,811 (6,634-18,387)	$1,285,271
ER Asthma Visits	113	15	31	$299 (222-414)	$9,151
Asthma Attacks	9,540	1,266	2,587	$41 (15-69)	$105,527
Upper Respiratory Symptoms	9,420	1,250	2,555	$24 (9-42)	$60,874
Lower Respiratory Symptoms	8,820	1,170	2,392	$15 (6-24)	$36,045
Work Days Lost	84,000	11,143	22,779	$106 (N/A)	$2,410,045
Minor Restricted Activity Days	432,000	57,308	117,150	$48 (20-78)	$5,673,597
Total					**$790,174,146**

[1] Number of incidences from power plant small particle pollution for the New Hampshire/Boston Consolidated Metropolitan Statistical Area (CMSA). Source: Abt Associates, October 2000

[2] Number of incidences for the New Hampshire portion of the CMSA (based on population ratios, then discounted slightly to account for improving air quality toward the northern portion of the CMSA).

[3] Number of incidences for the entire state due to transported small particle pollution (based on applying factors to account for all small particle pollution not just from power plants, the transported portion of the small particle pollution, the non-CMSA portion of the state, and improving air quality toward the northern counties of the state).

[4] Source: Abt Associates, October 2000. Ranges in valuations are given in parentheses.

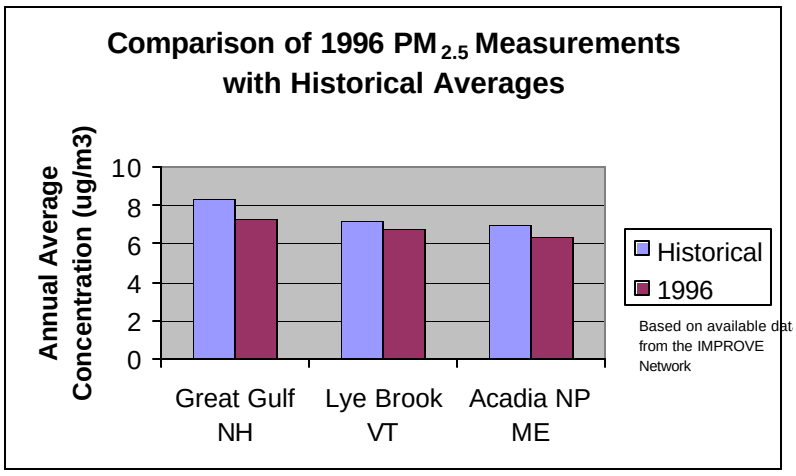
[5] Total valuation for New Hampshire from transported small particle pollution (multiply number of incidences by valuation per incident). Does not account for incidences related to heart attacks.

Valuations presented in Table B.1 are estimated only for $PM_{2.5}$ health effects and do no include valuations associated with ozone, mercury, and other materials that may or may not be toxic in nature. Estimated valuations do not account for damages done to the environment including contaminated water resources, vegetation and animal species shifting, and reduced forest and agricultural productivity. Increased cost of living and doing business including higher costs for fuels and vehicles in a designated non-attainment area (area of poor air quality) are also not accounted for in these valuations.

Calculation Methodology

Estimates of health impact valuations were initially conducted based on model results directly as reported in the Abt Associates, October, 2000 report. The Abt Associates study reported results on a state-by-state basis as well as based on entire Consolidated Metropolitan Statistical Areas (CMSAs). The modeling analyses in each case were based on the weather patterns that existed during 1996. NHDES reviewed how typical small particle concentrations were in the state during 1996 and found that while small particle concentrations in the southern portion of the state were near normal, the concentrations in the northern portion of the state were below normal, based on historical values from 2000-2003 (See Figure B.1). As a result, the health valuations computed from the Abt Associates modeling results are believed to be an underestimation of more typical values for the state. Therefore, an alternative method was developed to adjust Abt Associates modeled results to more representative values based on the most recent actual measured concentration data.

Figure B.1 - Comparison of 1996 to Historical Small Particle Concentrations Measured in and Near New Hampshire

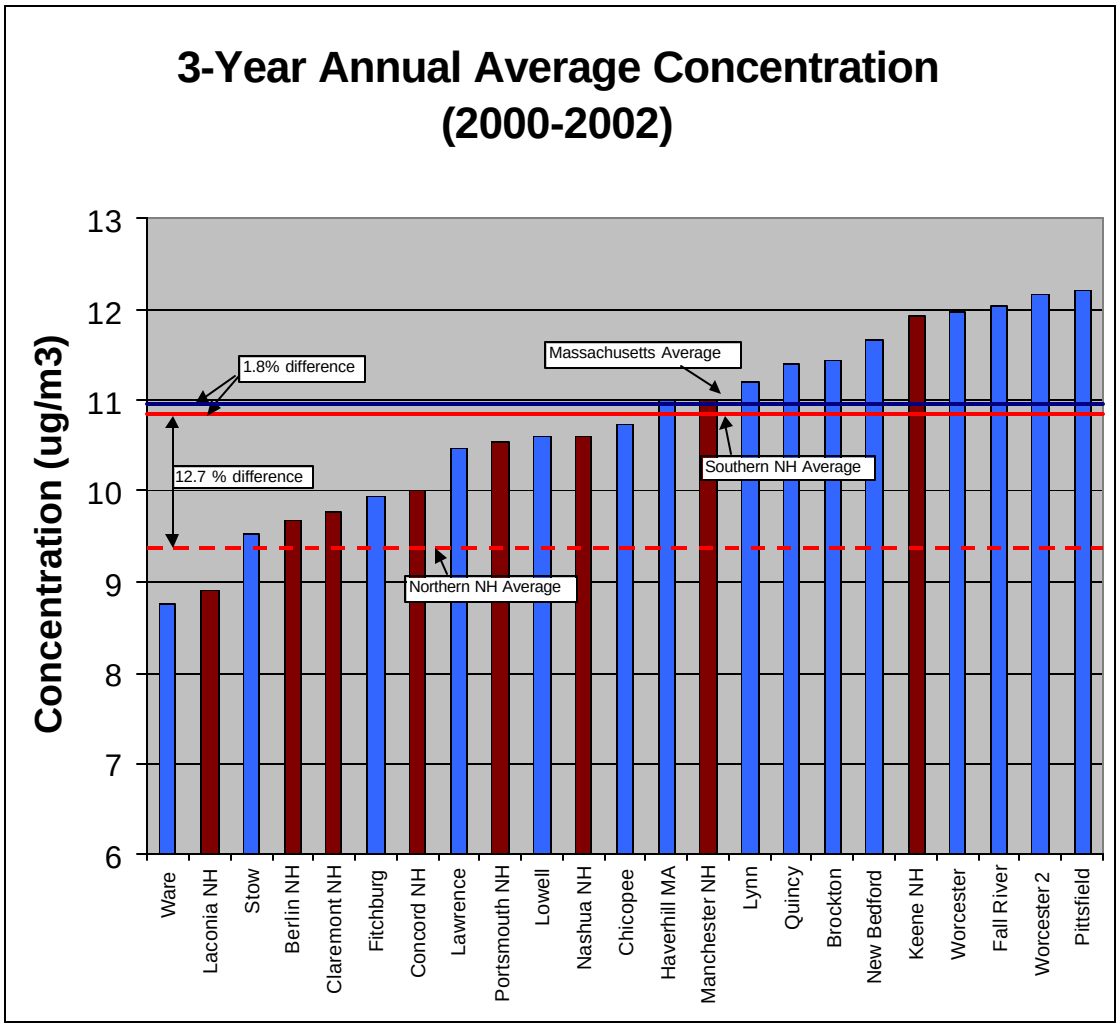


Note: Historical averages are from 2000 to 2003

In order to make the needed adjustments to the Abt Associates modeled values, estimates of typical small particle concentrations across the region were reviewed. Figure B.2 summarizes the three most recent years of small particle concentrations available across New Hampshire and the Boston CMSA (excluding downtown Boston where high levels of vehicle exhaust substantially effect localized small particle concentrations. These data were excluded since the Abt Associates report focuses on power plants emissions).

According to measurements of small particles from 2000 to 2002, the concentrations in the southern portion of New Hampshire (i.e., New Hampshire portion of the Boston CMSA) are about a 1.8 percent lower than those in the Massachusetts portion of the CMSA. The small particle concentrations in northern New Hampshire are another 12.7 percent lower than those measured in the southern part of the state.

Figure B.2 - Recently Measured Small Particle Concentrations in New Hampshire and the Boston Consolidated Metropolitan Statistical Area (CMSA)



The adjustments to the Abt Associates report model for the best estimate calculations of typical New Hampshire small particle health impact valuations are detailed in Table B.2. The first column gives the number of power plant health incidences from the Abt Associates report for the full Boston CMSA. The second column isolates the southern New Hampshire portion of the Boston CMSA (based on 13.51 percent of the total CMSA population) and adjusts the rate of incidences downward by 1.8 percent from the rates used for Massachusetts to account for the lower small particle concentrations measured in southern New Hampshire. The third column

adjusts from a power plant only scenario to a scenario of all manmade small particles using a factor based on speciated small particle concentrations measured in the region (see Figure 2.10 in the main text). This factor (1.67) assumes that all of the 57.1 percent of sulfate is from power plants and that all of the 4.5 percent of soil particles are not manmade and not transported. A 92 percent transport factor was then applied to estimate the number of health incidents due to transport of small particles into the state. The 92 percent factor for transport is the lowest factor calculated within the state and is conservatively applied throughout the state for long-term ozone exposure based on photochemical modeling. Its application to small particles is reasonable because of the known similarities in their transportability and is also supported by small particle modeling performed by EPA in support of the Clear Skies Act.

To account for the entire state, the northern portion of New Hampshire was added into the state estimates on a population basis (using a factor of 1.38 derived from the total state population versus New Hampshire areas of the Boston CMSA). The rate of incidences in the northern areas of New Hampshire were reduced 12.7 percent below the rates used for the southern part of New Hampshire based on measured concentrations. Finally, the New Hampshire-estimated small particle health incidents were multiplied by the Abt Associates health valuations.

Table B.2 - Adjusted New Hampshire Small Particle Health Valuations (Best Estimate)

	(Abt) Power Plants Boston	Power Plants New Hampshire portion of CMSA adjusted by 1.8%	New Hampshire Portion of CMSA Total Transport Caused	New Hampshire Total Transport Caused northern counties adjusted by 12.7%	(Abt) Mean Valuation Factor	Total Transport Valuation
Premature Mortality	454	60	93	123	$ 6,120,000.00	$ 753,472,724
Chronic Bronchitis	302	40	62	82	$ 331,000.00	$ 27,107,858
Acute Bronchitis	839	111	171	228	$ 57.38	$ 13,055
Hospital Admissions	320	42	65	87	$ 14,811.00	$ 1,285,271
ER Asthma Visits	113	15	23	31	$ 298.62	$ 9,151
Asthma Attacks	9,540	1,266	1,947	2,587	$ 40.79	$ 105,527
Upper Respiratory Symptoms	9,420	1,250	1,923	2,555	$ 23.83	$ 60,874
Lower Respiratory Symptoms	8,820	1,170	1,800	2,392	$ 15.07	$ 36,045
Work Days Lost	84,000	11,143	17,146	22,779	$ 105.80	$ 2,410,045
Minor Restricted Activity Days	432,000	57,308	88,181	117,150	$ 48.43	$ 5,673,597
Projected 2007 Population	6,991,988	944,546				
% of CMSA	100	13.51			**Total**	**$ 790,174,146**

Sulfate Component	0.571	(regional avg.)
Soil Component (non-transport)	0.045	(regional avg.)
Total Transportable Components	0.955	
Ratio of total to sulfate	1.67	
Transportable Pollutants from out of state	0.92	(Lowest NH rate)
Adjusted Ratio of power plants to all transported	1.54	

Hillsborough (Abt)	374,566
Merrimack (Abt)	132,658
Rockingham (Abt)	308,542
Strafford (Abt)	128,780
NH portion of Boston CMSA	944,546
Non-CMSA Counties	355,454
2000 Statewide Census	1,300,000
Growth Rate Factor (assumed)	1
Estimated 2007 NH population	1,300,000
Ratio of state total to CMSA portion	1.38

PM2.5 Mass

	% SO4-based	% Soil
Lye Brook, VT	57.4	4.5
Acadia NP, ME	56.8	4.5
Average	57.1	4.5

IMPROVE Annual Average (1996-99)

Percent NH CMSA portion is lower than Massachusetts portion	Percent 1.8
Percent northern NH is lower than NH-CMSA portion	12.7

Note: These adjustments were made because the Abt modeling used the year 1996 had larger than normal concentration changes between southern and northern New Hampshire (off by about 12%). Modeled results in the southern part of the Boston CMSA were fairly typical for 1996. Therefore, adjustments were made from Abt modeling Boston CMSA results using factors derived from 2000 - 2002 measured fine particles throughout the region.

Methodology Validation

EPA analyses of the economic costs and benefits for the Clear Skies Act of 2003 (CSA), Clean Air Planning Act of 2003 (CAPA), and the Clean Air Interstate Rule (CAIR) are provided in Table B.3. This health benefit data was used to validate the estimates made in Tables B.1 and B.2. For this validation, premature mortality, chronic bronchitis and emergency room asthma visits plus hospital admission incidents from Table B.1 (Total New Hampshire Estimated Incidences) were used as a benchmark to estimate what portion of EPA's total health benefits are attributable to New Hampshire. For example, using New Hampshire's 123 incidents of premature mortality to compare against the 6,400 incidents nationwide and a national $55 billion overall benefit, can give an approximated New Hampshire benefit by multiplying 123 by $55 billion and then dividing by 6,400. Based on premature mortality factors, New Hampshire's portion of the national total health benefits is $1.07 billion per year in the year 2010. Continuing this process using the other factors for 2010 and 2020 provides a range of $1.07 to $1.17 billion for 2010 and $1.16 to $1.26 billion for 2020. These approximations are close to, but greater than the $790 million estimation provided in Table B.1, indicating that this report's best estimate is valid and conservative. Uncertainties specific to the Abt Associates study are summarized in Table B.4 and ranges of valuations used are listed in Table B.1.

Table B.3 - EPA Clear Skies Act (CSA), Clean Air Planning Act (CAPA) and Clean Air Interstate Rule (CAIR) Cost and Benefit Estimations (1999$)

	2010			2015	2020	
	CSA	CAPA	CAIR	CAIR	CSA	CAPA
Premature Mortality	6,400	9,600	9,622	13,029	11,900	17,800
Chronic Bronchitis	3,900	5,800	5,200	6,900	7,400	10,900
ER/Hospital Admissions	5,600	8,400	16,000	22,500	10,400	15,500
Total Health Benefits[1]	$55 billion	$65 billion	$57 billion	$82 billion	$110 billion	$140 billion
Incremental Costs[2]	$4.4 billion	$5.6 billion	$2.9 billion	$3.7 billion	$6.3 billion	$8.7 billion
Health Benefit to Cost Ratio	13 : 1	12 : 1	20 : 1	22 : 1	18 : 1	16 : 1

[1] EPA changed the valuation methodology for the Clean Air Interstate Rule, adjusting for inflation and downgrading the value of premature death by about 13%. This also affects benefit-to-cost ratios.

[2] Cost differentials are between controls already required under the Clean Air Act and completion of obligations under the proposed Act or Rule. The Clean Air Interstate Rule does not include emission controls for mercury.

Source: EPA Clear Skies 2003 and Clean Air Interstate Rule 2004 websites and NHDES

Table B.4 - Key Areas of Uncertainty in Abt Associates Report, 2000

1. Uncertainties Associated with Concentration-Response (C-R) Functions
   - The value of the PM-coefficient in each C-R function.
   - Application of a single C-R function to pollutant changes and populations in all locations.
   - Similarity of future year C-R relationships to current C-R relationships.
   - Correct functional form of each C-R relationship.
   - Extrapolation of C-R relationships beyond the range of PM concentrations observed in the study.

2. Uncertainties Associated with PM Concentrations
   - Estimating future-year baseline daily PM concentration.
   - Estimating the change in PM resulting from the control policy.

3. Uncertainties Associated with PM Mortality Risk
   - No scientific literature supporting a direct biological mechanism for observed epidemiological evidence.
   - Direct causal agents within the complex mixture of PM responsible for reported health effects have not been identified.
   - The extent to which adverse health effects are associated with low level exposures that occur many times in the year versus peak exposure.
   - Possible confounding in the epidemiological studies of $PM_{2.5}$ effects with other factors (e.g., other air pollutants, weather, indoor/outdoor air, etc.).
   - The extent to which effects reported in the long-term studies are associated with historically higher levels of PM rather than the levels occurring during the period of study.
   - Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.

4. Uncertainties Associated with Possible Lagged Effects
   - What portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels would occur in a single year, and what portion might occur in subsequent years.

5. Uncertainties Associated with Baseline Incidence Rates
   - Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates.
   - Current baseline incidence rates may not well approximate what baseline incidence rates will be in the year 2030.
   - Projected population and demographics—used to derive incidences – may not well approximate future-year population and demographics.

6. Uncertainties Associated with Economic Valuation
   - Unit dollar values associated with health are only estimates of mean WTP and therefore have uncertainty surrounding them.
   - Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates due to differences in income on other factors.

7. Uncertainties Associated with Aggregation of Monetized Benefits
   - Health benefits estimates are limited to the available C-R functions. Thus, unquantified benefit categories will cause total benefits to be underestimated.

Source: Abt Associates, 2000

TECHNICAL ATTACHMENT C
OZONE HEALTH VALUATION CALCULATIONS

Table C.1 below represents the best estimate of health risk valuation for ozone for the State of New Hampshire. The estimated annual transport represents the difference between the natural (background) ozone and the actual ozone levels measured at the monitoring site. This difference can be translated into a health-related cost value using an established health valuation. A detailed methodology for the associated calculations follows this table.

Table C.1 - Projected Health Risk Values Due to Ozone Transport Into New Hampshire

County/Monitor	Estimated Annual Ozone (ppb)	Long-term Transport Factor[1]	Estimated Annual Transport (ppb)[2]	County Population (2000 census)	Estimated Annual Health Valuations for Ozone[3] (1999$)
Belknap / Laconia	33.9	0.96[4]	14.9	56,325	$16,593,983
Carroll / Conway	27.5	0.92	8.4	43,666	$7,242,563
Cheshire / Keene	25.6	0.99	7.1	73,825	$10,360,398
Coos / Pittsburg	23.4	0.99	4.9	33,111	$3,203,238
Grafton / Haverhill	27.8	0.99	9.3	81,743	$15,035,162
Hillsborough / Nashua	27.3	0.97	10.4	380,841	$78,630,147
Merrimack / Concord	22.0	0.96	5.3	136,225	$14,241,506
Rockingham / Portsmouth	27.8	0.94[5]	10.6	277,359	$58,074,814
Strafford / Rochester	28.3	0.95	11.2	112,233	$24,805,457
Sullivan / Claremont	27.0	0.99[6]	8.5	40,458	$6,780,115
State Totals	**--**	**0.96**	**--**	**1,235,786**	**$234,967,382**

[1] Based on 24-hour ozone mass-weighted averages derived from modeling of multiple ozone events.
[2] Estimates for different counties were derived based on ozone season relative difference from Haverhill and Manchester.
[3] Estimated health valuations based on $19.80 (Levy et al., 2001) applied per part per billion of annual ozone per person (1999$).
[4] Used factor for Concord.
[5] Used factor for Rye.
[6] Used 0.99 as a conservative estimate since the actual factor rounded to 1.00.

Sources of health data: Levy et al., December, 2001 and ALA, 2003

Calculation Methodology

In order to apply the valuation factor calculated in the Harvard study (Levy et al., 2001), annual ozone concentrations are needed. New Hampshire began year-round ozone monitoring at two locations (Manchester and Haverhill) in 2001. The data collected from these locations provide the basis for interpolating annual ozone concentrations throughout the state. The data were also used to estimate how much of that ozone is naturally occurring and should, therefore, not be included in any transport calculations.

Table C.2 shows monthly ozone average concentrations at Manchester and Haverhill. In order to isolate the manmade component, the lowest daily ozone concentrations within each month were identified and shown in the table as the *low estimate of natural* ozone. This assumes that circumstances were such that manmade ozone was not able to form under prevailing weather

conditions, a conservative assumption that lessens the manmade impact valuation. Then, based on photochemical modeling of only naturally occurring emissions, maximum day-to-day ozone variations were identified to approximate the *high estimate of natural* ozone concentrations. Modeling indicated that this maximum variation was about 15 parts per billion, thus 15 ppb was added to the low-natural estimate, producing a high-natural estimate. Next, a mid-point between the high and low was calculated to approximate an average natural ozone concentration, shown as the *mid estimate of natural*. The difference between this mid-natural estimate and the monthly measured ozone concentrations (at both Manchester and Haverhill) is assumed to be the manmade component. Finally, percent transport factors determined by long-term photochemical modeling were applied to estimate the manmade ozone transported into New Hampshire at both locations.

Table C.2 - Estimation of Annual Ozone Transport (in parts per billion) for Haverhill and Manchester

Manchester	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Avg**
Measured at Manchester[1]	20.5	22.5	27.0	33.0	30.5	32.8	31.8	29.8	22.2	17.5	14.5	18.0	25.0
High Estimate of Natural[2]	19	22	23	29	28	33	31	26	23	21	16	17	24
Low Estimate of Natural[3]	4	7	8	14	13	18	16	11	8	6	1	2	9
Mid Estimate of Natural[4]	11.5	14.5	15.5	21.5	20.5	25.5	23.5	18.5	15.5	13.5	8.5	9.5	16.5
Difference of Measured and Mid Natural	9.0	8.0	11.5	11.5	10.0	7.3	8.3	11.3	6.7	4.0	6.0	8.5	8.5
Estimated transport to Manchester[5] (manmade)	8.6	7.7	11.0	11.0	9.5	7.0	8.0	10.8	6.4	3.8	5.8	8.2	**8.2**
Haverhill	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Avg**
Measured at Haverhill[1]	27.0	32.0	35.0	38.7	34.3	30.0	26.3	27.0	22.7	20.0	19.0	21.5	27.8
High Estimate of Natural[2]	32	35	25	37	27	25	26	22	23	25	15	19	26
Low Estimate of Natural[3]	17	20	10	22	12	10	11	7	8	10	0	4	11
Mid Estimate of Natural[4]	24.5	27.5	17.5	29.5	19.5	17.5	18.5	14.5	15.5	17.5	7.5	11.5	18.4
Difference of Measured and Mid Natural	2.5	4.5	17.5	9.2	14.8	12.5	7.8	12.5	7.2	2.5	11.5	10.0	9.4
Estimated transport to Haverhill[5] (manmade)	2.5	4.5	17.3	9.1	14.7	12.4	7.7	12.4	7.1	2.5	11.4	9.9	**9.3**

[1] Monthly average measured 24-hour ozone concentration.
[2] High natural is assumed to be 15 ppb above the minimum (based on sensitivity NHDES modeling).
[3] Low natural is derived from low measured concentration for monitor.
[4] Mid estimate of natural is average of high and low estimates.
[5] Transport factors for New Hampshire applied as 96% of the difference for Manchester and 99% for Haverhill and are used to assess manmade ozone (difference between mid-point estimate of natural ozone for the month and the measured amount). Calculated transport factors for each county, as determined by NHDES modeling of multiple ozone episodes, are used below to estimate transport of manmade ozone throughout the entire State.

Because the majority of the ozone monitors in New Hampshire operate only during the summer months when ozone is most likely to form, estimates of annual ozone are needed to better estimate statewide ozone transport. The first step in estimating annual ozone is to identify

each monitor as either urban/suburban or rural in order to account for wintertime chemical reactions that can reduce ozone concentrations due to local NOx emissions. Counties in the southeast portion of the state were considered urban/suburban (Hillsborough, Merrimack, Rockingham, and Strafford). The remainder of the state was considered rural (Belknap, Carroll, Cheshire, Coos, Grafton, and Sullivan). The urban/suburban locations were linked to annual ozone monitoring at Manchester and the rural locations were linked to Haverhill. To estimate geographical ozone distribution, ratios were calculated of each county's summer ozone concentrations, relative to summer ozone levels at Manchester or Haverhill (see Table C.3).

Estimates of county specific annual ozone were determined by multiplying this ratio by the annual ozone measured at either Manchester or Haverhill. For example, the annual ozone estimate at Conway equals the Conway summer season average ozone concentration divided by the Haverhill summer season average ozone concentration and then multiplied by the Haverhill annual average ozone concentration. The mid-estimate of annual natural ozone for Manchester or Haverhill was subtracted from the annual ozone estimate to produce an estimate for the manmade ozone component in each county. Percent transport factors determined by long-term photochemical modeling were then applied to estimate the manmade ozone transported into New Hampshire. Finally, the transported manmade annual ozone component was multiplied by the Harvard valuation factor (of $19.80 per person per ppb of annual ozone) and then multiplied by the county population.

Table C.3 - Estimation of Annual Ozone Transport Throughout New Hampshire

Manchester 24-hour ozone — Transport percentage factor 0.96

	Measured	Low Natural	High (Low +15)	Mid-Natural	Diff	Transported
jan	20.5	4	19	11.5	9.0	8.6
feb	22.5	7	22	14.5	8.0	7.7
mar	27	8	23	15.5	11.5	11.0
apr	33	14	29	21.5	11.5	11.0
may	30.5	13	28	20.5	10.0	9.6
jun	32.8	18	33	25.5	7.3	7.0
jul	31.8	16	31	23.5	8.3	8.0
aug	29.8	11	26	18.5	11.3	10.8
sep	22.2	8	23	15.5	6.7	6.4
oct	17.5	6	21	13.5	4.0	3.8
nov	14.5	1	16	8.5	6.0	5.8
dec	18	2	17	9.5	8.5	8.2
Avg	25	9.0	24.0	16.5	8.5	**8.2**

Haverhill 24-hour ozone — Transport percentage factor 0.99

	Measured	Low Natural	High (Low +15)	Mid-Natural	Diff	Transported
jan	27	17	32	24.5	2.5	2.5
feb	32	20	35	27.5	4.5	4.5
mar	35	10	25	17.5	17.5	17.3
apr	38.7	22	37	29.5	9.2	9.1
may	34.3	12	27	19.5	14.8	14.7
jun	30	10	25	17.5	12.5	12.4
jul	26.3	11	26	18.5	7.8	7.7
aug	27	7	22	14.5	12.5	12.4
sep	22.7	8	23	15.5	7.2	7.1
oct	20	10	25	17.5	2.5	2.5
nov	19	0	15	7.5	11.5	11.4
dec	21.5	4	19	11.5	10.0	9.9
Avg	27.8	10.9	25.9	18.4	9.4	**9.3**

Ozone Season Ratio factor to Manchester (urban NOx scavenging)

Concord	Nashua	Rochester	Rye	
0.88	1.09	1.13	1.11	Ratio factor
22.0	27.3	28.3	27.8	Est annual ozone
16.5	16.5	16.5	16.5	Mid-natural Manchester
5.5	10.8	11.8	11.3	Difference
0.96	0.97	0.95	0.94	Transport factor
5.3	**10.4**	**11.2**	**10.6**	Transported

Ozone Season Ratio factor to Haverhill (rural NOx scavenging)

Claremont	Conway	Keene	Laconia	Pittsburg	
0.97	0.99	0.92	1.22	0.84	Ratio factor
27.0	27.5	25.6	33.9	23.4	Est annual ozone
18.4	18.4	18.4	18.4	18.4	Mid-natural Haverhill
8.5	9.1	7.2	15.5	4.9	Difference
0.99	0.92	0.99	0.96	0.99	Transport factor
8.5	**8.4**	**7.1**	**14.9**	**4.9**	Transported

Note: Annual ozone measured only at Manchester and Haverhill NH. Annual average ozone concentrations were estimated based on ratios established during ozone season. Urban and rural monitor areas were separated to account for NOx scavenging during winter inversions (urban areas have lower ozone). Transport factors determined by modeling.

TECHNICAL ATTACHMENT D

COMPARISON OF FEDERALLY PROPOSED ELECTRIC GENERATING UNIT MULTI-POLLUTANT LEGISLATION

	NO_x Caps (million tons)	SO_2 Caps (million tons)	Mercury Caps (tons)	CO_2 Caps (billion tons)	Impact on States' Rights	Estimated Annual Incremental Costs (1999$)	Estimated Annual Benefits (1999$)[4] to Health (H) and Visibility (V)
2001 EPA Emissions[1] (National)	4.7	10.6	44.1[2]	2.4	--	--	--
Clear Skies of 2002 (S. 2815 & H.R. 5266) **(CSA 2002)**	2.1 by 2008 1.7 by 2018	4.5 by 2010 3.0 by 2018	26 by 2010 15 by 2018	None	Major	$3.69 Billion – 2010 $4.70 Billion – 2015 $6.49 Billion – 2020	$43 Billion (H) – 2010 $93 Billion (H) - 2020
Clear Skies of 2003 (S. 1844 & H.R. 999) **(CSA 2003)**	2.1 by 2008 1.7 by 2018	4.5 by 2010 3.0 by 2018	34 by 2010 (S. 1844) 26 by 2010 (H.R. 999) 15 by 2018	None	Major	$4.3 Billion – 2010 $4.4 Billion – 2015 $6.3 Billion – 2020	$54 Billion (H) – 2010 $55 Billion (H) – 2015 $110 Billion (H) - 2020 $3 Billion (V) - 2020
Clean Air Planning Act (Carper/Chafee/Gregg) (S. 3135) **(CAPA 2002)**	1.87 by 2008 1.7 by 2012	4.5 by 2008 3.5 by 2012 2.25 by 2015	24 by 2008 10 by 2012 **(70% reduction at each facility)**	2.564 by 2008 **(2005 levels)** 2.398 by 2012 **(2001 levels)**	Minor	$5.62 Billion – 2010 $8.68 Billion – 2020	$65 Billion (H) – 2010 $140 Billion (H) - 2020
Clean Air Planning Act (Carper/Chafee/Gregg/Bass) (S. 843 & H.R. 3093) **(CAPA 2003)**	1.87 by 2009 1.7 by 2013	4.5 by 2009 3.5 by 2013 2.25 by 2016	24 by 2009 10 by 2013 **(70% reduction at each facility)**	2006 levels by 2009 2001 levels by 2013	Minor	$5.62 Billion – 2010 $8.68 Billion – 2020 (based on CAPA 2002)	$65 Billion (H) – 2010 $140 Billion (H) – 2020 (based on CAPA 2002)
Clean Power Act (2003) (Jeffords/Reed) (S. 366 & H.R. 2042) **(CPA 2003)**	1.51 by 2009	2.25 by 2009	5 by 2009 **(with unit-by-unit controls)**	2.05 by 2009	None	Not Available	Not Available
2001 EPA Based Emissions[1] **29-state**[3]	3.9	9.7	35.4	1.9	--	--	--
Clean Air Interstate Rule (non-legislation)	1.6 by 2010 1.3 by 2015	3.9 by 2010 2.7 by 2015	None	None	None	$2.9 Billion[5] – 2010 $3.7 Billion[5] – 2015	$57 Billion[6] – 2010 $82 Billion[6] – 2015

[1] Clean Air Markets Division Emissions Scorecard 2001: National total for all electric generating units on EPA's Clean Air Market database including coal, oil and gas units available in Table B2 at http://www.epa.gov/airmarkets/emissions/score01/index.html. After audits and quality reviews, in April 2003 EPA revised the heat input values used to derive these emission estimates. The heat input values used to derive these emissions estimates reflect the April, 2003 update of the EPA's Clean Air Market database.

[2] Mercury emissions were estimated by multiplying the EPA's revised 2001 national heat input value in the April, 2003 update of the EPA's Clean Air Market database by a national average mercury emission rate of 0.0035 lbs Hg/billion Btu from the EGRID database.

[3] Under the EPA's proposed Clean Air Interstate Rule utility sources located in the State of Connecticut are controlled for ozone season NOx only.

[4] (H) indicates health benefits. (V) indicates visibility benefits.

[5] Does not include mercury emission controls.

[6] EPA changed the valuation methodology for the Clean Air Interstate Rule from what was used for the Clear Skies Act.

GLOSSARY

GLOSSARY
TERMS & ACRONYMS

AAL: Ambient Air Limits, New Hampshire limits on ambient air pollutant concentrations of 750 regulated toxic air pollutants (RTAPs) set for the protection of public health

Acid deposition: the deposition of acidic chemicals onto water or land through precipitation, fog, or the settling of dry particles; the primary components of acid deposition are nitric acid (HNO_3) and sulfuric acid (H_2SO_4), which form through the reactions of nitrogen oxides (NOx) and sulfur dioxide (SO_2), respectively, with other chemicals in the air

Acid Rain: the common term for the wet forms of acid deposition

Aerosols: tiny liquid and/or solid particles suspended in the air

AIRS: Aerometric Information Retrieval System, an EPA air pollution database and information center

ALA: American Lung Association, a national health organization for fighting lung diseases, with emphasis on asthma, tobacco control, and environmental health

Ambient: the outdoor environmental conditions for the area of interest

AMC: Appalachian Mountain Club, an organization that promotes the protection and enjoyment of the Appalachian region through conservation, recreation, and education

ANC: Acid Neutralizing Capacity, a measurement of the ability of a solution to resist changes in pH by neutralizing acidic inputs; a lower ANC denotes greater sensitivity and less resistance to acidic inputs

Anthropogenic: made by humans, produced by human activities

AQA: Air Quality Analysis workgroup, an OTAG workgroup responsible for identifying, characterizing, and assessing air quality and meteorological data used to evaluate the effects of air pollution transport on ozone nonattainment in the eastern United States

Attainment: refers to areas in which the level of a criteria pollutant meets and does not significantly contribute to areas that do not meet the National Ambient Air Quality Standards (NAAQS) for human health

Bioaccumulation: the process by which a contaminant enters the body more quickly than the body can remove it

Boundary Layer: the lowest part of the atmosphere in which air flow is directly affected by heating and cooling processes near the surface and the presence of objects and terrain features at the surface; may vary in height depending on atmospheric conditions, particularly with respect to day/night differences in surface temperature; corresponds to the region in which pollutants are mixed

BTU: British thermal unit, a measure of heat; one Btu is the amount of heat required to raise one unit mass of water by one unit of temperature

Buffering Capacity: the ability of a solution to neutralize acidic or basic inputs and maintain its pH without becoming more acidic or basic

CAA: Clean Air Act, a federal law that sets air pollution limits and guides states in creating and enforcing air pollution regulations; the Clean Air Act was passed in 1963, but the current policies are based on the 1970 version and the amendments of 1977 and 1990

CAIR: Clean Air Interstate Rule, multi-pollutant legislation proposed by EPA in December of 2003 for reducing emissions of nitrogen oxides and sulfur dioxide in District of Columbia and 29 eastern states, with a focus on states where power plant emissions significantly contribute to small particle and ozone pollution in downwind states; formally known as the Interstate Air Quality Rule (IAQR)

CALEV: California Low Emission Vehicle Program, emission reduction standards specific to California

CALGRID: California Photochemical Grid Model, a regional photochemical grid model

CAMNET: a network of hourly-updated, real-time visibility cameras located at scenic sites throughout the Northeast; organized by NESCAUM to raise public awareness of the effect of air pollution on visibility

CAPA: Clean Air Planning Act of 2003, multi-pollutant legislation proposed by Senators Carper, Chafee, and Gregg, and Congressman Bass for reducing emissions of nitrogen oxides, sulfur dioxide, mercury, and carbon dioxide through a national cap and trade program

Cap and Trade: a policy approach to controlling emissions that involves applying a cap, or limit, on the amount of total emissions of a specific pollutant from a group of affected sources; under this system, each source is provided a limited number of emissions allowances, each representing one ton of the pollutant, which the source may sell, trade, or save for future use

Carbon Dioxide: CO_2, a gas formed from the combustion of carbon where there is an excess of oxygen, may be produced by human activities that involve the burning of fossil fuels, forest fires, or other natural processes, such as the respiration or decay of living organisms; carbon dioxide is a major greenhouse gas that contributes to global warming through the greenhouse effect

Carbon Monoxide: CO, a poisonous gas formed from the combustion of carbon where there is an insufficient supply of oxygen, produced most commonly from incomplete combustion reactions in automobile engines and in smaller amounts from the incineration of organic matter; carbon monoxide inhibits oxygen uptake by red blood cells, elevated exposure can produce symptoms such as fatigue, reduced motor skills, and visual impairment, pose a risk to individuals with cardiovascular diseases, and, if concentrated without relief, can be fatal in a matter of minutes

Channeled Flow: middle elevation (650 to 2600 feet) air flow that may be interrupted by large-scale objects, such as mountains, hills, and valleys, but that are unaffected by lower, smaller objects, such as trees and buildings

Class I Areas: areas of special national interest for which the Clean Air Act provides the highest level of protection from visibility impairment; mandatory federal Class I areas include national parks over 6,000 acres, wilderness areas over 5,000 acres, and international parks that existed as of August 7th, 1977

CMSA: Consolidated Metropolitan Statistical Area, an area with a population of at least one million which may be divided into sub-metropolitan divisions consisting of highly urbanized areas with strong economic and social links internally and with other portions of the larger area; an example of a CMSA is the greater Boston area that includes parts of Connecticut, Maine, Massachusetts, and New Hampshire

CO: see "Carbon Monoxide"

CO_2: see "Carbon Dioxide"

CPA: Clean Power Act of 2003, multi-pollutant legislation proposed by Senators Jeffords and Reed for reducing emissions of nitrogen oxides, sulfur dioxide, and mercury, and carbon dioxide through a national cap and trade program

Criteria Pollutants: six principal pollutants for which EPA has established national ambient air quality standards for the protection of public health and the environment; the six criteria pollutants are ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, particulate matter, and lead

Crustal Material: particles of soil or dust made airborne by the grinding or stirring action of wind, weathering, construction, traffic, and other surface activities; crustal material contributes to regional haze, though, due to the larger size of these particles compared to the other haze-forming particles, it tends to drop out of the atmosphere more readily, reducing its relative contribution to haze in the eastern United States

CSA: Clear Skies Act of 2003, multi-pollutant legislation proposed by President Bush for reducing emissions of nitrogen oxides, sulfur dioxide, and mercury through a national cap and trade program

Daylight Heating Hours: the hours of the day when solar energy drives the vertical mixing of transport layers, generally 9am to 5pm

DES: see "NHDES"

Diurnal Variation: fluctuations within the day/night daily cycle

Downwind: in the direction toward which the wind is blowing

EGRID: Emissions and Generation Resource Integrated Database, an EPA database containing air quality information related to electric power generation in the United States

EGU: Electric Generating Unit, fossil fuel-fired combustion unit that has a generating capacity greater than 25 megawatts-electrical output (MWe) and serves a generator producing electricity for sale

Elemental Carbon: particles consisting of inorganic carbon compounds produced from fuel combustion, primarily as soot from diesel exhaust and wood smoke; elemental carbon contributes to regional haze, mostly through the absorption, rather than the scattering, of light, and can produce winter-time "brown clouds" visible over urban areas and in mountain valleys

EPA: Environmental Protection Agency, an agency of the United States federal government charged with leading the nation's environmental policy efforts

Episode: an air pollution incident in a given area caused by elevated concentrations of atmospheric pollutants causing a significant health hazard

Exceedance: pollutant levels that exceed the levels of the NAAQS and may or may not constitute a violation of the standard

Greenhouse Effect: the warming of the Earth's atmosphere due to the presence of certain atmospheric gases, called greenhouse gases; shorter-wavelength solar radiation from the Sun passes through greenhouse gases and is absorbed by the Earth's surface, part of the absorbed energy is then reradiated back into the atmosphere as longer-wavelength infra-red radiation that cannot completely penetrate the greenhouse gases, these gases absorb some of the infra-red radiation, containing heat energy within the Earth's atmosphere and causing a warming effect

Greenhouse Gas: a gas that contributes to the warming of the Earth's atmosphere, called the greenhouse effect, by absorbing infra-red radiation radiated from the Earth's surface; the major greenhouse gases are water vapor, carbon dioxide, methane, nitrous oxide, and fluorocarbons

Half-distance: the distance traveled by a pollutant from where it is produced to the point at which its concentration has been reduced by one half; half-distance is similar to the concept of half-life in radioactivity

HAP: Hazardous Air Pollutants, toxic air pollutants known or suspected to cause serious health effects, such as cancer and birth defects, or have harmful environmental impacts; there are 188 EPA-regulated hazardous air pollutants, including benzene, cadmium, dioxin, and mercury

Haze: see "Regional Haze"

Heavy-Duty Vehicles: any motor vehicle, excluding passenger cars, with a weight over 6,000 lbs; examples include cargo vans, commercial trucks, and buses

Heavy-Duty Diesel Standards: Emissions standards set by EPA and effective in 2004 as part of a two-part strategy, the second stage beginning in 2007, for using advanced emissions controls to reduce emissions from heavy-duty vehicles, including highway trucks and buses

Hg: see "Mercury"

HNO_3: see "Nitric Acid"

H_2SO_4: see "Sulfuric Acid"

IAQR: Interstate Air Quality Rule, former name of the Clean Air Interstate Rule; see "CAIR"

IMPROVE: Interagency Monitoring of Protected Visual Environments, a monitoring program coordinated through a steering committee of federal, regional, and state organizations to evaluate visibility impairment in Class I areas of the United States by identifying sources and measuring the concentrations of visibility-reducing pollutants, assessing visibility conditions, and tracking progress toward national goals of visibility improvement

Inversion: an atmospheric condition in which temperature increases with elevation, creating a layer of warmer air that traps the underlying cooler air and is of interest because of the possibility of trapping and building up air pollutants near the ground that might otherwise be dispersed

Jet Stream: a relatively narrow band of strong winds that flows west to east in the upper troposphere in middle latitude and subtropical regions of both hemispheres and drives the movement of weather systems around the world

Light-duty Vehicles: any passenger vehicle that seats no more than 12 people; examples include passenger cars, mini-vans, and sport-utility vehicles

LLJ: see "Low-level Jet"

Low-level Jet: a ribbon of fast-moving air in the lower levels of the atmosphere; low-level jets common in the northeast generally consist of strong (40-50 mph) west to southwest winds developing during overnight and early morning hours, usually between 1,000 and 2,000 feet above ground level and flows along the eastern side of the Appalachian Mountains

LRS: Lower Respiratory Symptoms, such as wheezing and shortness of breath

MACT: Maximum Achievable Control Technology, a level of control specific to each industry source category that is required by the Clean Air Act for hazardous air pollutants based on the maximum degree of emissions reductions achievable with the available technologies for that source category

MADEP: Massachusetts Department of Environmental Protection

MANE-VU: Mid-Atlantic/Northeast Visibility Union, a regional state and tribal planning organization for coordinating regional haze planning activities in the northeastern and mid-Atlantic states established to improve visibility in Class I areas, thus meeting the EPA regional haze requirements; members include Connecticut, Delaware, District of Columbia, Maine Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, the Penobscot Indian Nation, Rhode Island, the St. Regis Mohawk Tribe, and Vermont

MBTU: one thousand British thermal units, a measure of heat

MEDEP: Maine Department of Environmental Protection

Mercury: a highly toxic heavy metal released into the air largely through coal and oil combustion in any of three forms: elemental mercury ($Hg_{(0)}$), oxidized mercury ($Hg_{(II)}$), and particle mercury ($Hg_{(P)}$); mercury can accumulate in the environment, especially through aquatic food chains; human ingestion of mercury, through fish consumption for example, can result in damage of the central nervous system and the brain and is a particular concern for pregnant women because mercury can reach the fetus and cause developmental problems

MMBTU: one million British thermal units, a measure of heat

NAAQS: National Ambient Air Quality Standards, national limits on ambient air pollutant concentrations set for the protection of public health and welfare by the EPA for the six criteria pollutants, including ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, particulate matter, and lead

NARE: North Atlantic Regional Experiment, an international research project on the effect of ozone on the chemistry of the atmosphere over the North Atlantic Ocean

NARSTO/NE: North American Research Strategy for Tropospheric Ozone – Northeast, the northeastern United States section of a tri-national, public-private partnership for dealing with multiple features of tropospheric pollution, including ozone and suspended particulate matter

NASA: National Aeronautics and Space Administration, a federal agency leading scientific and technological research and activities related to space and aeronautics

Near Surface Flow: low elevation (below 650 feet) air flow that is affected by nearly all surface frictional objects, including trees and buildings

NESCAUM: Northeast States for Coordinated Air Use Management, an interstate association of air quality control divisions in the Northeast states; member states include Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont

NHDES: New Hampshire Department of Environmental Services

Nitrates: (commonly ammonium nitrate), particles that form from reactions of nitrogen oxide gas, which is released from most combustion activities, such as through vehicle exhaust and power plant emissions; nitrates contribute to regional haze, especially in humid conditions when the accumulation of water causes the nitrate particles to grow in size and become more efficient at scattering light; nitrates may also transform into nitric acid in the atmosphere to become part of acid rain

Nitric Acid: HNO_3, produced by reactions between nitrogen oxide gases and water; a major component of acid rain

Nitrogen Oxides: (or oxides of nitrogen), NOx, the result of the oxidation of nitrogen, usually created by the intense heating of naturally occurring nitrogen in the air; a major component of photochemical smog, a precursor to the formation of ground level ozone, may lead to nitrate deposition and acid deposition

Nocturnal Boundary Layer: a fairly shallow (about 650 feet or less), stable layer with calm or light winds that forms low to the ground during the nighttime hours when surface cooling creates an inversion within which temperature increases with elevation

Non-EGU: Non-electric Generating Unit, a fossil fuel-fired combustion unit that has a maximum heat input rating greater than 250 million British thermal units per hour (mmBTU/hr) and does not serve a generator producing electricity for sale or that has a generating capacity of 25 MWe or less and serves a generator producing electricity for sale

Non-road Engines: mobile source engines that are not used for transport by road or highway; examples include agricultural equipment, construction equipment, utility generators and pumps, lawn and garden equipment, airport baggage transport vehicles, marine engines, snowmobiles, locomotives, and non-military aircraft; also called off-road engines

Northeast Corridor: a region along the East Coast that encompasses Washington DC, Baltimore, Philadelphia, New York, and Boston; the Northeast Corridor is a common path for ozone transport moving up the coast into the New England states

Nonattainment: refers to areas which measure or significantly contribute to areas that measure criteria pollutant concentrations failing to meet the National Ambient Air Quality Standards (NAAQS) for human health

NOx: see "Nitrogen Oxides"

NOy: total reactive nitrogen oxides, NOy includes aged and oxidized NOx species

NSR: New Source Review, a federal program under the Clean Air Act that sets control requirements and emission limits for the construction of new major sources and for major modifications to existing sources that will result in a significant increase in emissions; NSR requires facilities to obtain a clean air permit demonstrating use of the best available control technology on the new or modified source

O_3: see "Ozone"

Off-road Engines: see "Non-road Engines"

Ohio River Valley: the area surrounding the Ohio River, which follows the northern borders of West Virginia and Kentucky and the southern borders of Ohio, Indiana, and Illinois, flowing from Pittsburgh, Pennsylvania to Cairo, Illinois, where it meets the Mississippi River near the junction of the Illinois, Missouri, and Kentucky borders; this region has a high density of coal-fired power plants

On-road Engines: mobile source engines that are used for transport by road or highway; examples include passenger cars, passenger vans, sport-utility vehicles, trucks, buses, and motorcycles

Organic Carbon: particles consisting of compounds in which carbon is bonded to hydrogen that may be emitted directly or produced through reactions of gaseous hydrocarbons that are emitted from sources such as vehicle exhaust, vehicle refueling, solvent evaporation, and industrial processes; organic carbon is the second largest contributor to regional haze in the eastern United States

OTAG: Ozone Transport Assessment Group, a national workgroup for addressing issues related to ground-level ozone and long-range air pollution transport across the eastern United States; formed in 1995 to investigate the existence and nature of ozone transport, OTAG conducted extensive modeling and statistical analyses to describe the patterns of transport and aid in the development of strategies for downwind areas to reach ozone attainment; OTAG members include the 37 eastern-most states and other interested stakeholders field area; the effort concluded in 1997

OTC: Ozone Transport Commission, a regional organization established by Congress in 1990 to address the problem of ozone transport in the northeastern and mid-Atlantic states; members include Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and a northeastern section of Virginia

OTC NOx MOU: Ozone Transport Commission NOx Memorandum of Understanding, an agreement signed in September of 1994 by members of the Ozone Transport Commission, except Virginia, for reducing regional NOx emissions through a cap and trade system applied to utilities and large industrial boilers in the Ozone Transport Region (OTR) for two target years, 1999 and 2003, for the purpose of lessening ozone pollution in the OTR

OTR: Ozone Transport Region, the portion of the northeastern and mid-Atlantic region of the United States that consists of the members of the Ozone Transport Commission

Ozone: O_3, a molecule consisting of three oxygen atoms bonded together; ozone exists naturally in the stratosphere as a protective and insulating layer that absorbs ultra violet (UV) radiation from the sun; ozone also occurs naturally in small amounts at ground level but most ground level ozone is the result of anthropogenic pollution and is generated through photochemical reactions among its precursors, volatile organic compounds and nitrogen oxides, in the presence of sunlight; ground level ozone is a major component of photochemical smog and can cause damage to the respiratory system

Ozone Aloft: Ozone present at about 2000 feet or more above ground level

Ozone Response Curve: a theoretical curve describing the relationship of how ozone responds to varying levels of its precursor species, nitrogen oxides and volatile organic compounds

PAMS: Photochemical Assessment Monitoring Stations, monitoring stations required under the 1990 Clean Air Act Amendments for serious, severe, and extreme ozone nonattainment areas that collect detailed data on ozone and its precursors, nitrogen oxides and volatile organic compounds

pH: a measurement of acidity or alkalinity on a scale of 1 to 14, where 7 is neutral, less than 7 is acidic, and greater than 7 is alkaline (basic); pH is the negative log10 of the hydrogen ion concentration

Photochemical Smog: a visible cloud of air pollution usually composed of ozone, organic compounds, nitrogen oxide gases, particles, and/or sulfate particles

Photosynthesis: the process of converting light energy into chemical energy; green plants and other photosynthetic organisms use light energy, carbon dioxide, and water to synthesize sugars and other energy-rich organic compounds and release oxygen as a by-product

Plume: a visible concentration of pollutants that appears as an elongated band, whose shape and behavior varies under different atmospheric conditions, that is released into the atmosphere from an identifiable point of origin

$PM_{2.5}$: suspended particles less than 2.5 micrometers in diameter; small particles can cause respiratory damage, may be toxic or carcinogenic, and are a component of regional haze

PM_{10}: coarse suspended particles between 2.5 and 10 micrometers in diameter; large particles of this size are small enough to be inhaled into the lungs, although less readily than the smaller $PM_{2.5}$, and can exacerbate respiratory problems, especially in areas close to the source, since the larger, heavier particles tend to stay airborne for shorter distances than the very fine particles

Precursor: a compound that, under the necessary conditions, will react to form a new product; for example, nitrogen oxides and volatile organic compounds will react in sunlight to create ozone and thus are both ozone precursors

Regional Haze: reduced visibility resulting from the scattering and absorption of light by particles and gases in the air; the five principal types of small particles contributing to haze in the eastern United States are sulfates, organic carbon, nitrates, elemental carbon or soot, and crustal material

Regulatory Certainty: the passage of laws that aid businesses in planning cost-effective, long-term control strategies by providing insight into the types of control regulations that are expected to be put in place in future years based on the direction of current policy

Residence Time: the length of time a pollutant is present in the air in its current physical and chemical form

ROM: Regional Oxidant Model, a first generation photochemical model

RTAP: Regulated Toxic Air Pollutants, 750 toxic air pollutants that pose a significant risk to human health and/or the environment and for which the state of New Hampshire has set ambient air limits (AALs); this list of pollutants includes and expands upon the federally-regulated list of hazardous air pollutants (HAPs)

Sea Breeze: a coastal breeze blowing inland from the sea, caused by temperature differences between sea and land surfaces; when the land is warmed by the sun, the air begins to rise and is replaced by cooler air from over the water

SeaWiFS: Sea-viewing Wide Field-of-view Sensor Project, a NASA project that utilizes an Earth-orbiting ocean color sensor to collect quantitative data on global ocean bio-optical properties that is incorporated into a research data system for processing, calibrating, validating, archiving, and distributing the data to the Earth science community

SIP: State Implementation Plan, a set of regulations and planning materials assembled by a state and approved by the EPA that outlines the state strategy for implementing air pollution controls and meeting air quality standards and other requirements under the Clean Air Act

Small Particles: see "$PM_{2.5}$"

Smog: see "Photochemical Smog"

Soot: carbon-containing particles released during incomplete combustion of organic materials; see also "Elemental Carbon"

STAPPA/ALAPCO: State and Territorial Air Pollution Administrators/Association of Local Air Pollution Control Officials, two national associations that work closely together to enhance communication and coordination among air pollution officials of the federal, state, and local levels across the United States; STAPPA is an organization of the leadership of state, territorial, and tribal air pollution control agencies; ALAPCO is an organization of the leadership of city, county, and regional air pollution control agencies

Stratosphere: the layer of the atmosphere directly above the troposphere, usually between 10 and 30 miles above the Earth; this level contains the naturally-occurring ozone layer

Sulfates: (commonly ammonium sulfate), particles that form from reactions of sulfur dioxide gas, which is released from coal burning and other industrial sources; sulfates, primarily as ammonium sulfates, are the largest component of fine particulate matter contributing to haze in the eastern United States, especially in humid conditions when the accumulation of water causes the sulfate particles to grow in size and become more efficient at scattering light; sulfates may also transform into sulfuric acid in the atmosphere to become part of acid rain

Sulfur Dioxide: SO_2, the principally emitted form of the sulfur oxide gas; sulfur dioxide can cause or aggravate respiratory problems, and it is a major contributor to regional haze and acid deposition

Sulfuric Acid: H_2SO_4, produced by reactions between sulfur oxide gases and water; a major component of acid rain

Synoptic Flow: high elevation (above 2600 feet) air flow that is almost exclusively directed by large-scale weather systems and is unaffected by large-scale frictional ground level objects such as mountains, valleys, and lakes

Tier II Standards: Emissions standards set by EPA and effective in 2004 for all light-duty vehicles, including passenger cars, light trucks, minivans, and SUVs; the new standards average 0.07 grams per mile of nitrogen oxides and are a significant reduction from previous standards

Trajectory: the path followed a moving air mass, often used as a back trajectory to go back in time to see where the air came from

TBTU: one trillion British thermal units, a measure of heat

Troposphere: the lowest layer of the atmosphere, extending up to about ten miles above the Earth; this level contains most of the manmade air pollutants

UAM-V: Urban Airshed Model, a three-dimensional photochemical grid model and the primary model used in the OTAG analyses

UMD: University of Maryland

Upwind: in the direction from which the wind is blowing

Urban Airshed: an area surrounding a city or highly populated area in which the air is frequently confined with all parts of the area being subject to similar conditions of urban air pollution derived mainly from motor vehicles, industrial plants, combustion and heating plants, etc.

URS: Upper Respiratory Symptoms, such as sore throat and runny or stuffed nose

VA/HUD: Veteran Affairs/Housing and Urban Development, departments of the United States Federal Government

VOC: see "Volatile Organic Compounds"

Volatile Organic Compounds: VOC, numerous species of organic compounds or hydrocarbons that change into a vapor at a relatively low temperature; may be hazardous by themselves and may contribute to ozone and haze formation

VTDEC: Vermont Department of Environmental Conservation

Wind Field: the speed and direction of the wind over an area at any given time, may be visually represented by wind flags overlaying a map

WTP: Willingness To Pay, the amount that someone is willing to pay to acquire a good or service or achieve a certain result

Zero-threshold Pollutant: a pollutant for which no level of exposure is considered safe due to health effects proven to occur at levels far below the current national ambient air quality standards; primary examples are ozone and small particles

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